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An Assessment of the Viability of LandScan Data to Estimate Structure Location in Wildland Fire Management and Planning

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By

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Research indicates firefighting costs in the wildland-urban interface (WUI) are highly correlated with the number of homes threatened by wildfire. Therefore, knowing the location of structures is paramount for planners and fire managers attempting to reduce the threats posed to structures by wildfire, and for the attainment of land management goals and objectives for reducing hazardous fuels surrounding them. Yet, no national-level structure location dataset exists.

Previous attempts, such as the SILVIS Lab's product, to predict structure location and the extent of the WUI have relied on Census block-level data. While urban Census blocks are generally small in area, those corresponding to sparsely settled areas may contain many square miles of territory. Rural Census blocks can contain small clusters of homes in one area, but any large uninhabited regions in the remaining area can result in an average structure density that is lower than the federal WUI criteria. Additionally, the designation of an entire large Census block as WUI, when only a small portion of the block contains houses, simultaneously causes both an underestimation in the number of Census blocks that contain areas meeting the density criterion and overestimates the extent of the WUI.

LandScan USA, created by researchers at the Oak Ridge National Laboratory, estimates the population distribution for the United States using Census block-level housing data and additional inputs including transportation infrastructure, land cover, elevation, and cultural criterion, such as recreational features, retail establishments, employment, and educational locations.

In order to test the accuracy of the LandScan USA dataset for predicting structure locations in the WUI, this study measures the spatial coincidence between this dataset and county-level cadastral data in northwest Montana and compares those results to the SILVIS data. Additionally, each dataset was buffered 1½-miles and compared for spatial coincidence to measure the potential of the LandScan USA data to predict the location of the WUI.

The findings reveal that the LandScan USA data do not adequately predict the location of structures for use in wildfire management and planning. However, this research does indicate that further research into LandScan USA's ability to demarcate the WUI is justified.

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LIST OF ACRONYMS

BIA	(DOI) Bureau of Indian Affairs
BLM	(DOI) Bureau of Land Management
CWPP	Community Wildfire Protection Plan
DHS	(US) Department of Homeland Security
DOD	(US) Department of Defense
DOE	(US) Department of Energy
DOI	(US) Department of the Interior
FEMA	(DHS) Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FPA	Fire Program Analysis
FPU	Fire Planning Unit
FWS	(DOI) United States Fish and Wildlife Service
GAO	(US) Government Accountability Office
HFRA	Healthy Forests Restoration Act of 2003
KIA	(Cohen's) Kappa Index of Agreement
NAD83-Albers	North American Datum of 1983 with an Albers equal-area conic projection
NLCD	(USGS) National Land Cover Dataset
NPS	(DOI) National Park Service
NRIS	Montana Natural Resource Information System
NWMT	Northwest Montana (Fire Planning Unit)
ORNL	(DOE) Oak Ridge National Laboratory
RAVAR	Rapid Assessment of Values-At-Risk
SILVIS	University of Wisconsin-Madison Forest and Ecology Laboratory
UN	United Nations
US	United States
USDA	(US) Department of Agriculture
USFS	(USDA) Forest Service
USGS	(DOI) United States Geological Survey
WFDSS	Wildland Fire Decisions Support System
WGS84	World Geodetic System of 1984
WUI	Wildland-Urban Interface

I. INTRODUCTION

1. Context

Wildland or rangeland fires (including those in grasslands, forests, and scrublands) are uncontrolled fires, that may be caused by people or by natural processes (State of Montana, 2007). We cannot stop wildfire from occurring; our attempts to do so through the suppression of wildland blazes for most of the 20th century has resulted in a fire management situation that is more complex and difficult to administer (USDA and DOI, 2001a; Missoula County Office of Emergency Services, 2005; USDA-OIG, 2006; GAO, 2008). A consequence of aggressively and effectively suppressing wildfire is the increase in undergrowth and density of trees, creating high levels of fuels that, when burned, result in high-intensity fires that threaten the lives of the public and firefighters, private and public property, and critical natural resources, especially in areas that are commonly referred to as the Wildland-Urban Interface (WUI; USFS, 1999; GAO, 2007; GAO, 2008). The United States Forest Service (USFS) identifies the WUI as the zone where structures and other human developments meet, or intermingle with, undeveloped wildlands (Fire and Aviation Management, 2008).

Due to the accumulation of fuels, severe weather and drought in some areas of the country (related in part to climate change), and growing numbers of homes built in or near wildlands, the appropriations for wildland fire management activities have risen from about $1 billion in fiscal year 1999 to more than $3 billion in fiscal year 2007 (GAO, 2008). Relative costs have also escalated; wildfire suppression accounted for 10-15% of the USFS budget in the 1990s, whereas it now comprises more than 40% of the budget (Gebert, 2007). Firefighting costs are highly correlated with the number of homes threatened by a fire; when large forest fires burn near homes, costs associated with the protection of structures usually exceed $1 million per fire (Rasker, 2008). According to Rasker (2008), the pattern of housing development (i.e., dense clusters vs. scattered holdings and sprawl) is an important contributing factor to wildland fire suppression costs. Therefore, knowing the location of structures is paramount for planners and fire managers to make informed decisions towards reducing the threat posed to structures by wildfire and towards the attainment of land management goals and objectives for reducing hazardous fuels surrounding them.

2. Problem

No national-level building/structure location dataset currently exists, although the US Department of Homeland Security (DHS) is working with various local, State, Federal, and Tribal government agencies to start that process (FGDC, 2005; USGS, 2006; DHS, 2008; FGDC - CDS, 2008b). According to the United States Departments of Agriculture (USDA) and Interior (DOI) as published in the Federal Register (USDA and DOI, 2001b: 753), "a structure is understood to be either a residence or a business facility, including Federal, State, and local government facilities; structures do not include small improvements such as fences and wildlife watering devices". Due to the lack of consistent locational data for structures, existing alternatives such as parcel data (RMRS, 2008a) and Census population data (Dobson et al., 2000; Radeloff et al., 2005; Theobald and Romme, 2007) have been employed to estimate potential impacts from wildland fire. Analyzing aerial orthophotos is too time-intensive to provide real-time decision support, is less reliable in areas with a dense canopy, and is dependent on often-dated aerial photographs (FGDC - CDS, 2007).

In areas where the presence of structures (or lack thereof) can be extracted from cadastral data, those records are maintained at the county level; for instance, Montana's state-run, state-wide cadastral download website is updated by the individual counties themselves by submitting their data to the Montana Department of Revenue, which then, in turn updates the website. The methodology (both the acquisition of and content therein of the data) and accuracy (both spatial and non-spatial) of cadastral data varies from county to county (even in Montana) and state to state; no national standard exists.

Studies that employ US Census data, such as the SILVIS Lab at the University of Wisconsin, compute housing density by dividing the total number of housing units within each Census block by the area of the respective Census block to identify where housing density exceeds one housing unit per 40 acres (Stewart et al., 2003). The boundaries of Census blocks typically follow visible physical features (e.g., streets, roads, streams, and railroad tracks) and invisible boundaries (e.g., property lines or city, town, township, and county boundaries). While urban Census blocks are generally quite small in area, those corresponding to sparsely settled areas may contain many square miles of territory (US Census, 2001). This can result in large Census blocks with a small cluster of homes in one area, but large uninhabited regions in the remaining area creating an average density too low to meet the WUI criteria set forth in the Federal Register (Stewart et al., 2009). It can also result in the designation of an entire large Census block as WUI where only a small portion of the block contains housing units (Leonard, 2007). "This has the effect of both underestimating the number of Census blocks that contain areas that meet the density criteria and overestimating the area of that 'community'" (Wilmer and Aplet, 2005: 12). To work around this problem, studies have used ancillary data in dasymetric[1] mapping (Wilmer and Aplet, 2005; Hammer et al., 2007; Theobald and Romme, 2007) to modify the boundaries of Census blocks omitting areas where people typically do not reside, such as public lands; however, although private inholdings within the national forests are rare in the western US (where public land designation predates widespread settlement of the region),

[1] "Dasymetric mapping as a procedure is applied to data sets for which the underlying statistical surface is unknown, but for which aggregation are not derived from the variation in the underlying statistical surface but are rather the result of some convenience of enumeration. The *process* of dasymetric mapping is thus the transformation of data from the arbitrary zones of data aggregation to a dasymetric map in order to recover and depict the underlying statistical surface" (Mennis and Hultgren, 2006: 180). In dasymetric mapping, the transformation of data from the arbitrary zones of the original source data to the meaningful zones of the dasymetric map incorporates the use of an ancillary data set that is separate from, but related to, the variation in the statistical surface (Eicher and Brewer, 2001).

eastern US forests may have extensive private residential settlements which would not be accounted for by masking public lands (Stewart, et al., 2009).

Establishing a national standard that identifies the likely locations of structures (and structure density) will allow for more informed decisions pertaining to wildland fire management and planning, especially in sparsely settled areas where local cadastral data are not available. Since the late 1990s, researchers at the United States Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) have been dedicated to using an innovative approach employing geographic information systems and remote sensing to pioneer the development, refinement, and updating of a global population database known as the LandScan Global Population Project (Bhaduri et al., 2002). While U.S. Census housing data provide the foundation for the LandScan population information, the researchers at the ORNL include additional parameters (e.g., transportation routes, cultural landmarks, land cover, elevation, etc) and therefore, do not rely entirely on the Census population data like most other studies (Bhaduri et al., 2007). And although the LandScan data do not represent structure locations, it is expected that there is strong spatial correspondence between the LandScan population counts and structure locations thus warranting their use in fire management and planning activities.

3. Research Questions

The goal of this research is to assess the viability of the LandScan population distribution database for the conterminous US as a nationally consistent standard for estimating structure location, and as a basis for determining the WUI to aid in wildland fire management and planning. Western Montana is used as a study area for this purpose for reasons that are described in the methods section. Accordingly, two separate but related research questions are proposed: 1) do the LandScan population distribution data predict the locations of structures derived from county cadastral data better than the SILVIS Census block-level data?; and 2) can the LandScan population distribution data be utilized as a basis to create a finer-scale WUI map than the Census block-level map from the SILVIS Lab?

II. LITERATURE REVIEW

Places in close proximity to national parks, national forests, and other natural amenities such as rivers, coasts, and mountains, etc. are becoming increasingly popular settlement destinations (Rasker and Hansen, 2000; Radeloff, et al., 2005; Hammer, et al., 2007; Theobald and Romme, 2007). As the population of the United States becomes increasingly dispersed, developing low-density housing (especially in rural areas where land is more affordable), each home is consuming more land and creating a more complex and expansive WUI (Theobald et al., 1997; USDA and DOI, 2001a; Hammer et al., 2004). Additionally, since 1970, more than 50% of population growth in the WUI has occurred in areas with high fire hazard (Hammer, et al., 2007; Theobald and Romme, 2007), and this trend is likely to continue (Gude et al., 2008; Rasker, 2008). Federal wildland fire policy directly affects the lives and property of those who live in the WUI (Hammer, et al., 2007; Theobald and Romme, 2007; Stewart, et al., 2009). This section outlines the ever-evolving wildland fire policy of the USFS, reviews terms associated with wildland fire, and describes the role of federal agencies and guidelines involved in wildland fire emergency response.

> “Like the question of slavery, the question of forest fires may be shelved for some time, at enormous cost in the end, but sooner or later it must be met. Every consideration of prudence and economy is on the side of prompt and thoroughgoing action.” (Pinchot, 1898)

1. Wildland Fire Policy of the United States Forest Service

In many parts of North America, Native Americans shaped the landscapes which Europeans (and European-Americans) saw as unaltered by humans, and fire was their primary tool; “there is no such thing as pure nature, no human-free wilderness, only lands where we work in concert with, instead of in ignorance of, natural processes” (Arno and Allison-Bunnell, 2002: xviii). American Indians are well-known to have set fires that did not destroy entire forests nor ecosystems, were relatively easy to control, and stimulated new plant growth (Williams, 2000). Indian-set fires differed from natural fires in their seasonality, frequency, and intensity (Lewis, 1985; Pyne, 1997). Reasons varied from tribe to tribe (not all tribes burned the landscape) and region to region, with most accounts indicating that Indians used fire to achieve “mosaics, resource diversity, environmental stability, predictability, and the maintenance of ecotones” (Lewis, 1985: 77). They are not alone in this use of fire, however. Managing wildland forests with fire is an ancient technique used by subsistence farmers and hunter-gatherers worldwide (Pyne, 1997).

The Forest Reserve Act of 1891 authorized the President to establish forest reserves “to save timber for the use of the people and to hold the mountain forests as great sponges to give out steady flows of water for use in the fertile valleys below” (Pinchot, 1907: 7). Management of the forest reserves became the responsibility of the newly created USDA Forest Service in 1905, consolidating Federal administration previously divided between the DOI’s General Land Office, the DOI’s United States Geological Survey (USGS), and the USDA Bureau of Forestry. The Fulton Amendment to the 1907 annual agricultural appropriations bill took away the President’s power to proclaim reserves, granting congress alone the authority to establish reserves; in addition, it changed the names of the ‘forest reserves’ to ‘national forests’ to clarify that the forests were to be used and not preserved (Williams, 2005a).

In the early twentieth century, American foresters and researchers debated the role of fire in the forest environment and the management policies between light-burning and fire suppression (Clements, 1910; Hoxie, 1910; du Bois, 1914; Greeley, 1920; Leopold, 1920; Show and Kotak, 1925; Chapman, 1926; Koch, 1935). The practice of light burning is the deliberate firing of forests at frequent intervals in order to burn up and prevent the accumulation of litter and ladder fuels thus preventing the occurrence of serious conflagrations (Leopold, 1920). Light-burning techniques were predominately employed by American foresters in the southeast and California regions. In the paper, “How Fire Helps Forestry,” Hoxie (1910: 146) wrote:

> …fire always has been and always will be the salvation and preservation of our California … forests, and no doubt the forests of many other states. …fire running at will is *master*. This is not the practical aspect. It is the intention to deal herein with fire as a *servant*, whose coming is to be prepared for in advance. This preparation can be undertaken successfully in the summer months and the servant fire can be put to work in the fall months, or after the first (season-ending) rains…

However, soon after becoming the first Chief of the Forest Service, Gifford Pinchot wrote, "Probably the greatest single benefit derived by the community and the nation from forest reserves is insurance against the destruction of property, timber resources, and water supply by fire…" (Pinchot, 1905: 63); this effectively established fire suppression as an important management policy of the USFS. Gifford Pinchot was a proponent of aggressive fire suppression:

> Though recognizing so clearly the role of fire in the regeneration of forests, Pinchot was prevented by his forestry education (in Europe) from seeing the significance of allowing fire to play a role in future management. Fire prevention was … a bedrock value of European forestry, developed in a wetter region where fires were less common. His professional answer to fire's role in the forest was that forest managers could take its place. Foresters would reseed the land after harvest. They would grow trees faster and more efficiently than nature. Eventually they would go a step further and replace fire with clear-cuts, mimicking the large openings and land disturbances on the landscape… Pinchot's unifying idea was scientific management (Barker, 2005: 80)

The fire management goal to efficiently suppress all fires, while not officially adopted by the USDA Forest Service until 1935, became implemented as a reaction to 'The Big Burn' of 1910, which was a series of 1,736 fires that scorched three million acres in northern Idaho and western Montana, including one-third of the town of Wallace, Idaho, killing 85-87 people (Miller and Cohen, 2001). Nonetheless, fire was not completely eliminated; light-burning continued in the southeastern United States, where most forest land was privately or state-owned (Pyne, 1982).

The “War on Fire” (Arno and Allison-Bunnell, 2002: 20) began, in earnest, in 1935 when the USFS established the ‘10AM policy’ which involved extinguishing any sighted fire by 10AM the day following its report (in 24 hours or less); if the control objective was not achieved, then firefighting forces would be mobilized for control by 10AM the following day, and so on. The USFS ‘armed’ itself with money and manpower made available under the Civilian Conservation Corps and the Works Progress Administration New Deal agencies (Williams, 2005a); “roads, trails, telephone lines, lookouts, fuelbreaks, hazard reductions, and guard stations, all appeared in the backcountry almost overnight” (Pyne, 1982: 275). The basic theory was to achieve the lowest total costs, including resource losses, through an all-out effort to keep every fire as small as possible; the ultimate cost of suppressing a large fire is many times the cost of extinguishing a good many small ones (Pyne, 1982). This policy did not identify benefits; it merely assumed they existed (Nelson, 1979). Pyne (1982: 286) notes that the 10AM Policy became “an entrenched part of the USFS bureaucratic reality and inheritance… not until 1967 was there a serious policy review; not until 1971 were there bona fide amendments; not until 1978 was the venerable 10AM Policy superseded by a wholly new policy” (Pyne, 1982: 290).

The wildfire suppression policy did not include a complimentary program to reduce the gradual accumulation of flammable organic materials (fuels) that occurred in many ecosystems when fires were suppressed; the wildfire suppression policy was ultimately self-defeating, because the resulting wildland fuel accumulation would eventually increase the risk of wildfire damages (Busenberg, 2004). Pyne (1994: 10) notes, “the environmental tragedy was not that wildfires were suppressed, but that controlled ones were no longer kindled”. Prophetically, Hoxie wrote in 1910, “Therefore it will surprise the majority of readers to learn that prevention of fire may be made so complete as to menace the forests with greater danger than they now incur” (Hoxie, 1910: 145). In 1977, the federal Office of Management and Budget, alarmed by the accelerating expenditures for fire suppression, advised land management agencies to develop more cost-effective fire policies. During the ensuing year, the *Forest Service Manual 5100: Fire Management* (USFS, 1978) document replaced previous policies and encouraged a pluralistic approach to fire management; even for suppression, once initial attack failed, alternatives were to be considered by the fire boss, possibilities that might or might not mean further efforts at suppression (Pyne, 1982). The new fire management policy directed federal agencies to achieve a balance between suppression (to protect life, property, and resources) and fire use (to regulate fuels and maintain healthy ecosystems). However, fire managers were required to fight the entire fire for suppression or allow the entire fire to burn for resource benefit until the latest policy guidelines were released that indicate wildland fires may now be concurrently managed for one or more objectives and those objectives can change as the fire spreads across the landscape (USDA and DOI, 2009).

Arno and Allsion-Bunnell (2002: 23) note that "just as the 1910 fires had been a defining event that helped launch the national fire suppression policy, the huge 1988 fires in the greater Yellowstone Park area strongly influenced the fledgling fire management policy". Complete reviews and updates of the federal wildland fire management policy, conducted jointly by the USDA and DOI in 1989, 1995, 2001, 2003, 2008, and again in 2009 (USDA and DOI, 2009), have concluded that allowing natural caused fires to burn for resource benefits (also known as wildland fire use) should continue; succeeding years saw the wildland fire use program reach maturity as lightning-caused fires (in Yosemite National Park) burned together into a jigsaw pattern and either went out or re-burned with reduced intensity (van Wagtendonk, 2007). Nonetheless, only a fraction (less than 2 percent) of fuels needed in most types of wildland forests to maintain historical ecological conditions or to reduce excessive accumulations of fuels has been allowed to burn (Arno and Allison-Bunnell, 2002). As long as the accumulation rate of fuels remains greater than the rate of treatment, over-accumulated biomass will continue to fuel severe wildfires that thwart our best efforts at control (Williams, 2005b). Fire management objectives must be directly related to resource values and the costs of protecting them, and that protection should be commensurate with values and risks (Nelson, 1979).

2. Risk Assessment Terminology

> Definitions are constructed and valid only within a given scope... They combine words with notions of, sometimes, complex phenomena in a unique way. Definitions are essential for reliable communication between involved people working on the same topic. They are used as 'abbreviations' for complex and difficult to explain matters. Definitions are never true or false, but useful or not useful within the scope they are applied (Bachman and Allgöwer, 2000: 2).

In our common vernacular, the terms threat, hazard, and risk are often used interchangeably; however, important distinctions exist between these terms. Confounding the problem, dictionaries, such as the American Heritage Dictionary of the English Language, will often use one of these terms to describe another, blurring the differences between these words (hazard, 2004; risk, 2004; threat, 2004). The following terminology, reviewed in the context of the relevant literature, will be used as defined below for the remaining pages of this document.

Threat

A threat exists when there is potential to experience harm; threat refers to the phenomenon that could cause that harm (Hyde, in press). A wildfire is a threat. However, if no valued resources are proximate to the wildfire, it does not pose any hazard nor risk. Suppressing a wildfire reduces the threat, but not necessarily hazard or risk.

Hazard

A hazard is a physical situation with a potential for human injury, damage to property, damage to the environment, or some combination of these (Bachman and Allgöwer, 2000). Hazard indicates that something else is needed (a threat) in order to convert potential to realized harm (Hardy, 2005). Therefore, a hazard occurs when any valued resource exists that could undergo harm from a specific threat; "a wildfire is determined *hazardous* where valued resources are possibly in harm's way, an unqualified judgment that fire might cause damage" (Hyde, in press). Thinning forest fuels in the WUI comprises hazard reduction.

Risk

Risk is the product of the probability of an undesirable event and the expected outcome, typically expressed as damage, of the event (Hardy, 2005). Analysis of risk explicitly requires assessment of the probability that a loss will occur (Hyde, in press). The undesirable event is the realization of a hazard (Bachman and Allgöwer, 2000). Therefore, risk quantifies the likelihood that a threat will occur and conveys the expected loss. In extension, a risk assessment is a management decision tool, generally proactive in nature that organizes and integrates different types of information estimating the likelihood and magnitude of an unwanted occurrence upon those values (Fairbrother and Turnley, 2005).

Risk Assessment Example

If a fire ignites in a forested region, the mere presence of flame is a threat. If a structure is proximate to the flames, the fire presents a hazardous condition relative to the structure (without knowing the probability that the flame with reach the structure, risk cannot be calculated). If the structure is valued at $200,000 and has a 25% chance that the fire will reach and engulf the structure, the structure is at-risk with expected loss of $50,000 (WFDSS, 2009). Accordingly, a wildland risk assessment quantifies all values proximate to the fire, including critical infrastructure as well as natural and cultural resources, and their expected loss to permit the triaging of emergency response equipment.

3. Fire Program Analysis

The *Review and Update of the 1995 Federal Wildland Fire Management Policy* report (USDA and DOI, 2001a), completed in January 2001, requires standardized training, data collection and analysis, and a standard interagency operational policy and procedure for planning and budgeting wildland fire events. Furthermore, the report noted that this system needs to be capable of expanding the regular and ongoing participation in fire management program management and implementation to all federal agencies with fire-related capability and responsibilities, including, but not limited to the Department Of Defense (DOD), DOE, the Bureau of Reclamation, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, the Federal Emergency Management Agency, the Natural Resources Conservation Service, and the USGS. Additionally, in 2001, the US Congress directed the US Departments of Agriculture and Interior to develop a coordinated and common system to determine readiness and improve the allocation of fire resources to improve effectiveness and efficiency (FPA, 2008b). The Fire Program Analysis (FPA) project is that system.

The FPA provides a common interagency (USDA and DOI) decision support tool for wildland fire planning and budgeting, enabling wildland fire managers in the five federal land management agencies (i.e., USFS, Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Fish and Wildlife Service (FWS), and the National Park Service (NPS)) to jointly plan and evaluate the effectiveness of fire management strategies for meeting fire and land management goals, while encouraging the participation of nonfederal wildland fire partners, including state, local, and tribal agencies (FPA, 2008b). It incorporates geospatial data which provide the means to map levels of wildland fire risk on lands across the country and generates outcomes from the Fire Planning Units (FPU) that inform the national budget planning process while providing a way for land managers to compare trade-offs between wildland fire program components (FPA, 2007).

The FPA divides the United States into over one hundred FPUs across the nation (Figure 1); of these, seven FPUs were selected as prototype areas: New

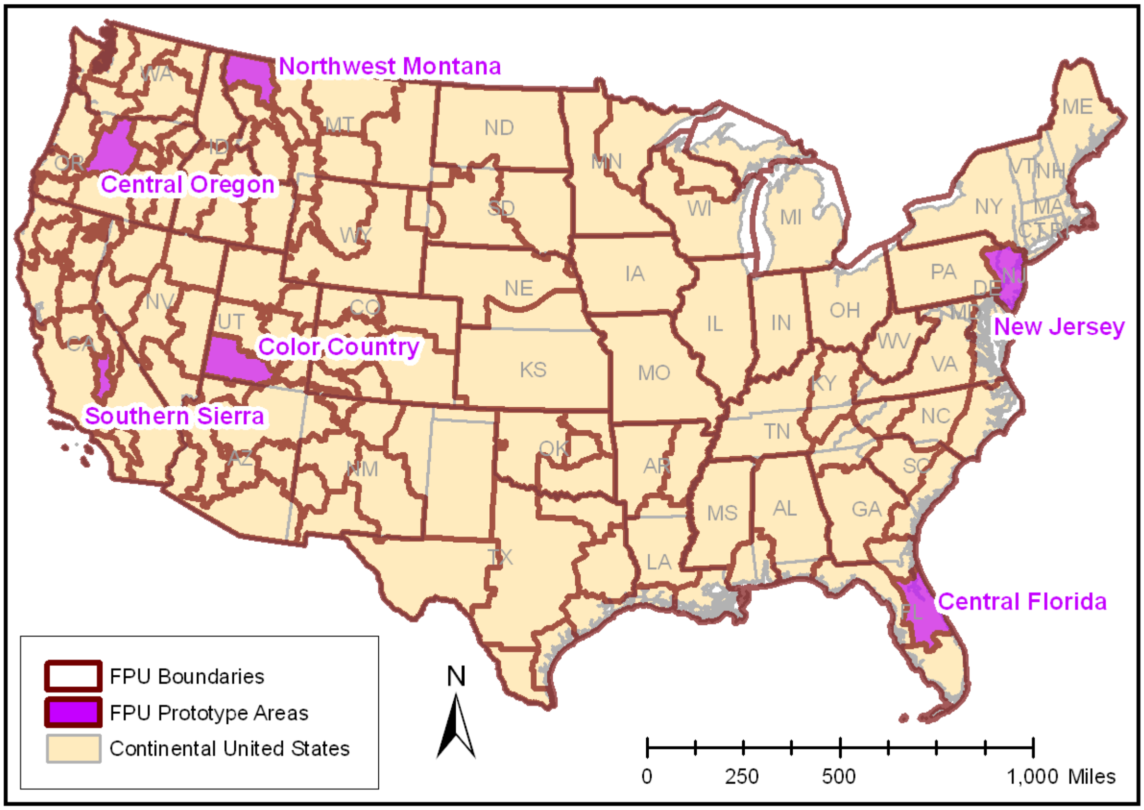


Figure 1. Continental United States Fire Planning Unit boundaries, as of 18 July 2008.

Jersey, Central Florida, Color Country in Utah, Northwest Montana, Central Oregon, Southern Sierra, and Alaska (not displayed). The FPU boundaries typically follow federal boundaries, such the national forests and national parks, and state boundaries. The FPU prototype area selection requirements included: ecological diversity from one FPU to another, multiple agency representation, proven spatial analysis capabilities, a minimum of a moderate level of fuels management activities such as WUI and ecosystem restoration, at least a moderate level of extended attack and large fire workload, a minimum of a moderate level of fire prevention workload, at least a moderate level of wildland fire occurrence, ties to LANDFIRE[2] prototype areas, and on-going interagency fire planning activities and line officers willing to participate (FPA, 2007).

[2] A geospatial data and modeling system designed to generate comprehensive maps of vegetation, fire, and fuel characteristics nationally (GAO, 2008)

The goal of the FPA prototype phase is to solidify system requirements and to evaluate all the component parts of the model that represent risk. Individual FPUs participating in the prototype phase will be testing one or more fire simulation models, data input processes, or user interface features to determine the most useful and efficient tools to meet budget planning needs (FPA, 2008a). The fire simulation models produce raster data predicting the fire probability and fire intensity for each FPU with a cell size of 270 m × 270 m (Finney, 2007). Each 270 m × 270 m cell equals 72,900 m^2, which in turn equals approximately 18 acres per cell.

4. Rapid Assessment of Values at Risk

The Rapid Assessment of Values at Risk (RAVAR) product, developed by the Rocky Mountain Research Station's Missoula Forestry Sciences Lab, is the primary fire economics tool within the Wildland Fire Decision Support System (WFDSS), which was developed by the USFS and is currently being adopted by DOI agencies, including the BIA, BLM, and NPS. RAVAR was initially developed in 2005 with further testing and prototype applications delivered during the 2006, 2007, 2008, and 2009 seasons (including over 100 RAVAR reports delivered through the web-based WFDSS to fire events in real time during both the 2007 and 2008 fire seasons). RAVAR is a spatial model that identifies primary resource values that are potentially threatened by or are at risk from ongoing fire events by rapidly identifying the spatial locations of highly valued resources, their proximity to ongoing fire perimeters, and the likelihood of a fire affecting these resource values over the duration of the fire (RMRS, 2008a). These data are essential to inform strategic decision making by the agency administrator and fire incident management teams (RMRS, 2008b). Any resource value that has been spatially mapped may be included within a WFDSS-RAVAR assessment, including power lines, road networks, gas pipelines, recreation facilities, sensitive wildlife habitat, cultural heritage sites and municipal water intakes; the most important data layer generated by the WFDSS-

RAVAR model is the structure layer using local parcel records that have shown to provide a reliable foundation for the prioritization of firefighting resources (USFS, 2007). Individual housing values are not used in wildland fire management and planning, although each structure is assigned the inflation adjusted average home value for the respective county in which it is located per Census data.

When wildfires occur in areas without cadastral data, a request is made to the USGS Rocky Mountain Geographic Science Center to analyze aerial photographs from the National Agricultural Imagery Program for structure presence. However, this is a time-intensive process often causing a full day's delay in the delivery of structure location estimates. Possessing a nationally-consistent structure estimation dataset for the entire country would dramatically increase the ability to deliver real-time RAVAR products when fires occur in areas without cadastral data and serve as a reference in areas with cadastral data.

5. Wildland-Urban Interface

The Wildland-Urban Interface has been defined in numerous ways ranging from general descriptions to detailed classification schemes. As mentioned previously, the USFS identifies the WUI as the zone where structures and other human developments meet, or intermingle with, undeveloped wildlands (Fire and Aviation Management, 2008). The Federal Emergency Management Agency calls it the area where homes and structures meet the natural environment of forests and wildlands (2005). According to FireWise, a public education program developed by the National Wildland Fire Coordinating Group that assists communities located in proximity to fire-prone lands, the WUI refers to a set of conditions under which a wildland fire reaches beyond natural fuels, such as trees and brush, to homes and their immediate surroundings (2008). The Utah Fire and Rescue Academy (2004: 1) at Utah Valley University states:

> Wildland urban interface does not lend itself to easy definition. In the broadest definition, wildland urban interface

> is when development of housing, recreation, and/or associated supporting facilities occurs in wildland fuels, which does not alter the basic structure or character of the original fuel type (will the surrounding fuels carry a fire). Classifying an area as an interface zone is a subjective decision; however, wildland fuels must be present to pose a threat to development.

In *The Wildland/Urban Interface Fire Problem* report to the Council of Western State Foresters, Teie and Weatherford (2000) define the WUI as existing where humans and their development meet or intermix with wildland fuels. These authors describe four different wildland/urban "conditions;" the Interface Condition, Intermix Condition, Occluded Condition, and the Rural Condition.

- <u>The Interface Condition</u> is where structures abut wildland fuels. There is a clear line of demarcation between the structures and the wildland fuels along roads or back fences. Wildland fuels do not continue into the developed area. The development density for an interface condition is usually 3 or more structures per acre.
- <u>The Intermix Condition</u> is where structures are scattered throughout a wildland area. There is no clear line of demarcation; the wildland fuels are continuous outside of and within the developed area. The development density in the intermix ranges from structures very close together to one structure per 40 acres.
- <u>The Occluded Condition</u> is a situation, normally within a city, where structures abut an island of wildland fuels (park or open space). There is a clear line of demarcation between the structures and the wildland fuels along roads or fences. The development density for an occluded condition is usually similar to those found in the interface condition and the occluded area is usually less than 1,000 acres in size.

- The Rural Condition is where scattered small clusters of structures (ranches, farms, resorts, or summer cabins) are exposed to wildland fuels. These structures or clusters are often miles apart.

The Wildland/Urban Interface Fire Problem report's (Teie and Weatherford, 2000) definitions are the basis from which the Federal Government's initial definition of *urban wildland interface communities at high risk* from wildfire originates (USDA and DOI, 2001b). However, the Intermix and Rural Conditions are aggregated into the Intermix Category, and one further criterion, a population density measure, is included in its definition of the WUI. The USDA and DOI (2001b: 753) notes within the Federal Register that, "generally, the Federal agencies will focus on communities that are described under categories 1 and 2 (Interface and Intermix)."

- Category 1: The Interface Community exists where structures directly abut wildland fuels. There is a clear line of demarcation between residential, business, and public structures and wildland fuels. Wildland fuels do not generally continue into the developed area. The development density for an interface community is usually 3 or more structures per acre, with shared municipal services. An alternative definition of the interface community emphasizes a population density of 250 or more people per square mile.
- Category 2: The Intermix Community exists where structures are scattered throughout a wildland area. There is no clear line of demarcation; wildland fuels are continuous outside of and within the developed area. The development density in the intermix ranges from structures very close together to one structure per 40 acres. An alternative definition of an intermix community emphasizes a population density of between 28-250 people per square mile.
- Category 3: The Occluded Community generally exists in a situation, often within a city, where structures abut an island of

> wildland fuels such as a park or open space. There is a clear line of demarcation between structures and wildland fuels. The development density for an occluded community is often similar to those found in the Interface Community, but the occluded area is usually less than 1,000 acres in size.

The SILVIS Lab (2008) at the University of Wisconsin derives its WUI definition from the Teie and Weatherspoon (2000) report and the descriptions located within the Federal Register (USDA and DOI, 2001b) defining the WUI as the area where houses meet wildland vegetation (interface WUI), or where houses and vegetation are mixed together (intermix WUI). Further literature delineating the difference between Interface and Intermix areas includes the USDA – Office of Inspector General, Western Region (USDA - OIG, 2006: 2) distinguishing as follows:

> Wildland urban interface is any area containing human developments, such as a rural subdivision, that may be threatened by wildland fires. Wildland intermix is an interspersing of developed land with wildland where there are no easily discernible boundaries between the two systems, such as an isolated cabin surrounded by forest.

The League of California Cities and the California State Association of Counties (2004: 4) differentiates between interface and intermix with the following definitions:

> Wildland Interface is the geographical meeting point of two diverse systems, wildland and structures. At this interface, structures and vegetation are sufficiently close that a wildland fire could spread to structures or a structure fire could ignite vegetation.
>
> Wildland Intermix is the interspersing of developed land with wildland, where there are no easily discernible boundaries between the two systems. Poses more problems in wildland fire management than interface.

Conceptually, the roles of various government entities are clearly defined, but in practice are not simple to apply. The roles of the federal government within the WUI are wildland firefighting, hazardous fuels reduction, cooperative prevention and education, and technical assistance; structural protection is the responsibility of tribal, State, or local governments. Federal agencies may assist with exterior structural protection activities under formal Fire Protection Agreements that specify the mutual responsibilities of the partners, including funding (USDA and DOI, 2001a). However, the cost of the USFS's wildland fire suppression efforts continue to escalate primarily from protecting private property in the WUI bordering USFS lands (USDA - OIG, 2006).

6. Community Wildfire Protection Plans

The Healthy Forests Restoration Act (HFRA) of 2003 (Public Law 108-148) places the onus on local and state representatives (with consultation with federal agencies) to determine the WUI and priority areas for local fuel treatments via a Community Wildfire Protection Plan (CWPP). CWPPs allow for community-based forest planning and prioritization while providing opportunities for communities to establish a localized definition and boundary for the WUI (Public Law 108-148, 2003). However, only limited guidance on methods and approach are delineated in the HFRA. Minimum requirements for a CWPP include that they: (a) must be collaboratively developed by local and state government representatives, in consultation with federal agencies and other interested parties; (b) must identify and prioritize areas for hazardous fuel reduction treatments and recommend the types and methods of treatment that will protect one or more at-risk communities and essential infrastructure; and (c) must recommend measures that homeowners and communities can take to reduce the ignitability of structures throughout the area addressed by the plan. These plans "can be as simple or complex as a community desires" (Communities Committee et al., 2004: 3) based on the needs of those involved in their development. The final contents of a CWPP must have mutual agreement between the applicable local government (i.e. counties/cities), the local fire department(s), and the state entity responsible for forest management.

A consequence of the flexibility inherent within the HFRA guarantees that a national WUI map produced by combining all of the locally created CWPPs will comprise great variability, decreasing its value as a national product to compare one region to another for the purpose of triaging fire management decisions. This disparity in standards is most evident in the border regions between states that created their WUI maps employing clearly differing standards. For example, much of Georgia is characterized as WUI, whereas in adjacent Alabama, with very similar terrain, very little area is designated as WUI. Similar boundary issues appear between Idaho and Washington, Oklahoma and Kansas, North Carolina and Tennessee, and Kentucky and its neighbors (Wilmer and Aplet, 2005).

According to the HFRA (Public Law 108-148, 2003: 1891-1892), communities without a CWPP will have their WUI defined as:

1. An area extending ½-mile from the boundary of an at-risk community;
2. An area within 1½-miles of the boundary of an at-risk community, including any land that:
    a. Has a sustained steep slope that creates the potential for wildfire behavior endangering the at-risk community;
    b. Has a geographic feature that aids in creating an effective fire break, such as a road or ridge top; or
    c. Is in condition class 3, as documented by the Secretary in the project-specific environmental analysis; and
3. An area that is adjacent to an evacuation route for an at-risk community that the Secretary determines, in cooperation with the at-risk community, requires hazardous fuel reduction to provide safer evacuation from the at-risk community.

7. Summary

Due to ongoing development, the consequences of fire management policies have their greatest effect in the constantly growing WUI (Hammer, et al., 2007; Theobald and Romme, 2007; Stewart, et al., 2009). Programs such as the FPA and WFDSS present a standard, sound management foundation providing managers with the latest scientific technology to guide decision support processes and document wildfire management decisions (FPA, 2008b; RMRS, 2008a). They employ a common framework for situational assessment and risk analysis while offering opportunities for managers to allow fire to fill its essential role in ecological processes and natural change ensuring that management programs and activities are economically viable based upon the values to be protected, costs, and land and resource objectives weighing the short and long term effects of both action and non-action alternatives (USDA and DOI, 2001a; FGDC - CDS, 2007). Federal coordination in the development of CWPPs facilitates collaboration between tribal, state, and local fire management organizations and the identification and reconciliation of gaps in protection responsibilities and goals; this also helps to clarify and refine hazardous fuel-reduction treatment locations, methods, and priorities to protect life, property, infrastructure, and valued resources (Communities Committee et al., 2008).

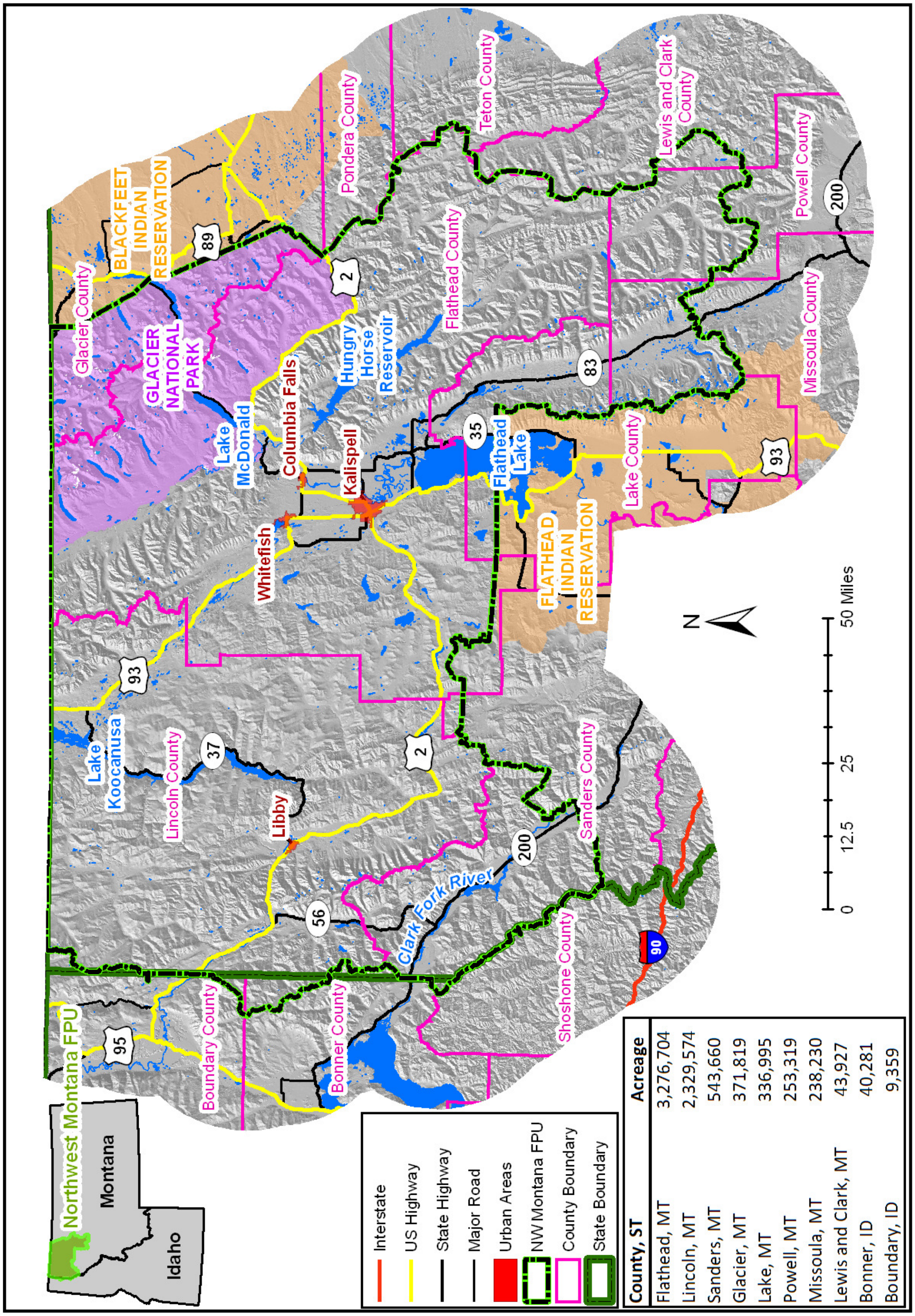
These collaborative policy implementation actions should help prevent the movement of wildfires from the wildlands into the WUI area, out of the WUI into the wildlands, and improve efficiency of wildfire suppression in WUI situations (USDA and DOI, 2001a; Communities Committee, et al., 2008; USDA and DOI, 2009).

III. METHODS

In order to ascertain the accuracy of the LandScan national population dataset in predicting the location of structures in areas affected by wildfire hazards, this study measures the degree of spatial correspondence of the LandScan population distribution dataset and structure locations derived from county cadastral data. In addition, the LandScan data and the cadastral data will undergo a buffer proximity analysis to estimate the WUI. Both the LandScan and cadastral-derived WUI maps will then be compared to the SILVIS WUI map, a current and widely referenced national-level product.

1. Study Area

The study area for this analysis is the Northwest Montana (NWMT) Fire Planning Unit, which is comprised of approximately 7.5 million acres (Figure 2). This FPU's extent is largely defined by the borders of the Kootenai and Flathead National Forests, and Glacier National Park. The mixed-conifer forest includes ponderosa pine, Douglas-fir, and larch. The NWMT FPU has a significant annual wildfire workload and is part of the 2006 LANDFIRE rapid assessment modeling and mapping zone (FPA, 2007). Agencies within the NWMT FPU that maintain wildland fire responsibilities include the USFS, NPS, FWS, and the State of Montana Department of Natural Resources and Conservation.



County, ST	Acreage
Flathead, MT	3,276,704
Lincoln, MT	2,329,574
Sanders, MT	543,660
Glacier, MT	371,819
Lake, MT	336,995
Powell, MT	253,319
Missoula, MT	238,230
Lewis and Clark, MT	43,927
Bonner, ID	40,281
Boundary, ID	9,359

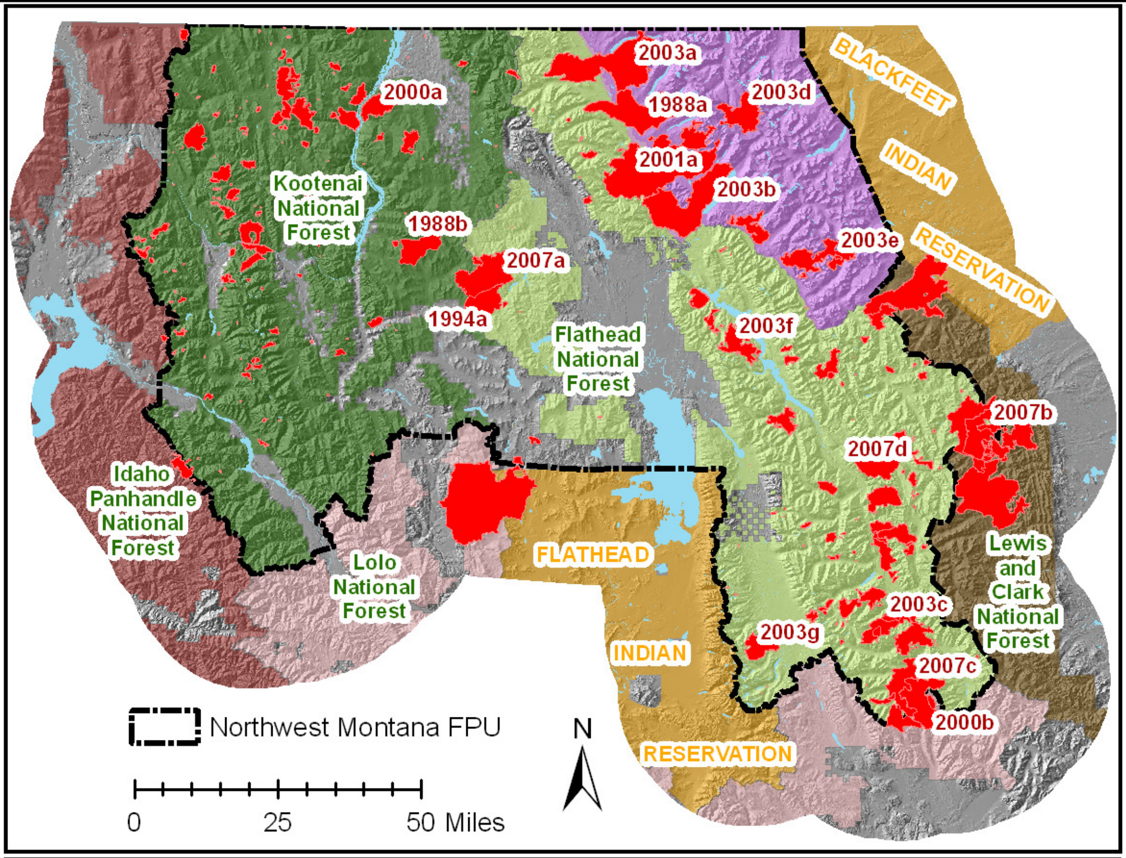
Figure 2. Study area regional overview.

The largest urban area within the Northwest Montana FPU is the community of Kalispell with approximately 20,000 people (US Census, 2007). The northern border of the FPU is demarcated by the United States-Canada international border. Therefore, Glacier National Park is completely within the study area, whereas, Waterton Lakes National Park is not. The Blackfeet Indian Reservation is located immediately east of the study area, and the Flathead Indian Reservation is located adjacent to the southern extent of the FPU, but is also not within the study area.

Seventy-five percent of the study area acreage is located within Flathead and Lincoln Counties, Montana; the remaining 25% of the study area is comprised by eight additional counties: Glacier, Lake, Lewis and Clark, Missoula, Powell, and Sanders Counties in Montana, and Bonner and Boundary Counties in Idaho (Idaho lands constitute less than 1% of the total area). The Clark Fork River is the largest river flowing through the NWMT FPU with the northern half of Flathead Lake, Lake Koocanusa, Hungry Horse Reservoir, and Lake McDonald constituting the major water bodies within the study area.

Communities in the vicinity of federal lands at risk from wildfire located within the Northwest Montana FPU include: Bigfork, Bull River Corridor, Condon, East Shore Flathead Lake, Essex, Eureka, Fortine, Heron, Highway 200 Corridor, Highway 93 Corridor, Hungry Horse, Kalispell, Kila, Libby, Marion, Noxon, Polebridge, Rexford, Saint Mary, Somers, Stryker, Swan Lake, Trego, Trout Creek, Troy, West Kootenai, Whitefish, and Yaak, MT (USDA and DOI, 2001c).

Over 300 fires have occurred within the boundaries of the NWMT FPU since 1985 (USFS, 2008). Figure 3 depicts all fires, with calculated acreage for the fires which burned over 10,000 acres, within the study area during the period 1985-2007 (both the Chippy Creek and the Skyland fires of 2007 burned over 10,000 acres in total, but minimal acreage within the study area).



Fire	Acreage Burned	Year/Label	Fire	Acreage Burned	Year/Label
Moose	70,569	2001a	Corporal	16,106	2007d
Wedge Canyon	53,322	2003a	Dry Fork	15,232	1988b
Robert	52,720	2003b	Little Wolf	15,086	1994a
Little Salmon Cr. Complex	50,187	2003c	Blackfoot Lake	14,191	2003f
Red Bench	34,639	1988a	Crazy Horse	11,281	2003g
Brush Creek	29,886	2007a	Stone Hill	10,913	2000a
Trapper Creek Complex	29,729	2003d	Monture Complex	10,457	2000b
Fool Creek	28,652	2007b			
Rampage Complex	21,629	2003e			
Railley	18,255	2007c			

Acreage burned within Northwest Montana FPU 1985 - 2007 (minimum of 10,000 acres)

Figure 3. Northwest Montana FPU wildland fires 1985 - 2007.

2. Data Collection

Cadastral Data

Cadastral data are currently being used by the WFDSS-RAVAR project to represent structure density regarding emergency response (FGDC - CDS, 2007). The RAVAR project accomplishes this by mapping the locations of structures based on the building values associated with each parcel of land (Calkin et al., in review). The data necessary for this analysis come from local government assessment offices, and must be updated annually. However, this dataset is not complete because some counties will not share their data (only a few) and some counties do not have parcel data that are, or can be, spatially enabled (this represents the majority of missing county data); approximately two-thirds of counties within the 11 western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) have provided their cadastral data for use within the WFDSS-RAVAR project that is categorized as response-ready (FGDC - CDS, 2008a; RMRS, 2008c).

Fortunately, cadastral information for the state of Montana is publicly available via the Montana Natural Resource Information System (NRIS) and the Montana Cadastral Mapping Project, a public-private sector partnership designed to create, maintain, and disseminate a digital GIS land ownership map database of the entire state (Bacino, 1999). Cadastral data are available for Boundary County, Idaho, and indicate no structures are located within the extent of the Northwest Montana FPU. Although it is unfortunate that cadastral data are not currently available for Bonner County, Idaho, no structures are expected within the extent of the NWMT FPU due to the geographical location and limited extent of the land area involved. Complete cadastral data coverage throughout the Montana portion of the NWMT FPU is one of the reasons why it was chosen as the study area.

The Montana cadastral dataset available from NRIS contains, but is not limited to, the spatial geometry of parcels and the value of any structures located on each parcel (NRIS, 2008). Properties denoted as having structure value were selected from the dataset, and a centroid was created for each selected parcel, generating a ‘building clusters’ dataset. The building clusters data underwent conversion from a point shapefile to a raster image that conforms and aligns with the other datasets involved in this study by calculating the number of building clusters per raster cell for the entire Northwest Montana FPU; these values were then classified according to the housing density criteria set forth by the USDA and DOI (2001b: 753) found in the Federal Register and refined by the SILVIS Laboratory (Figure 4).

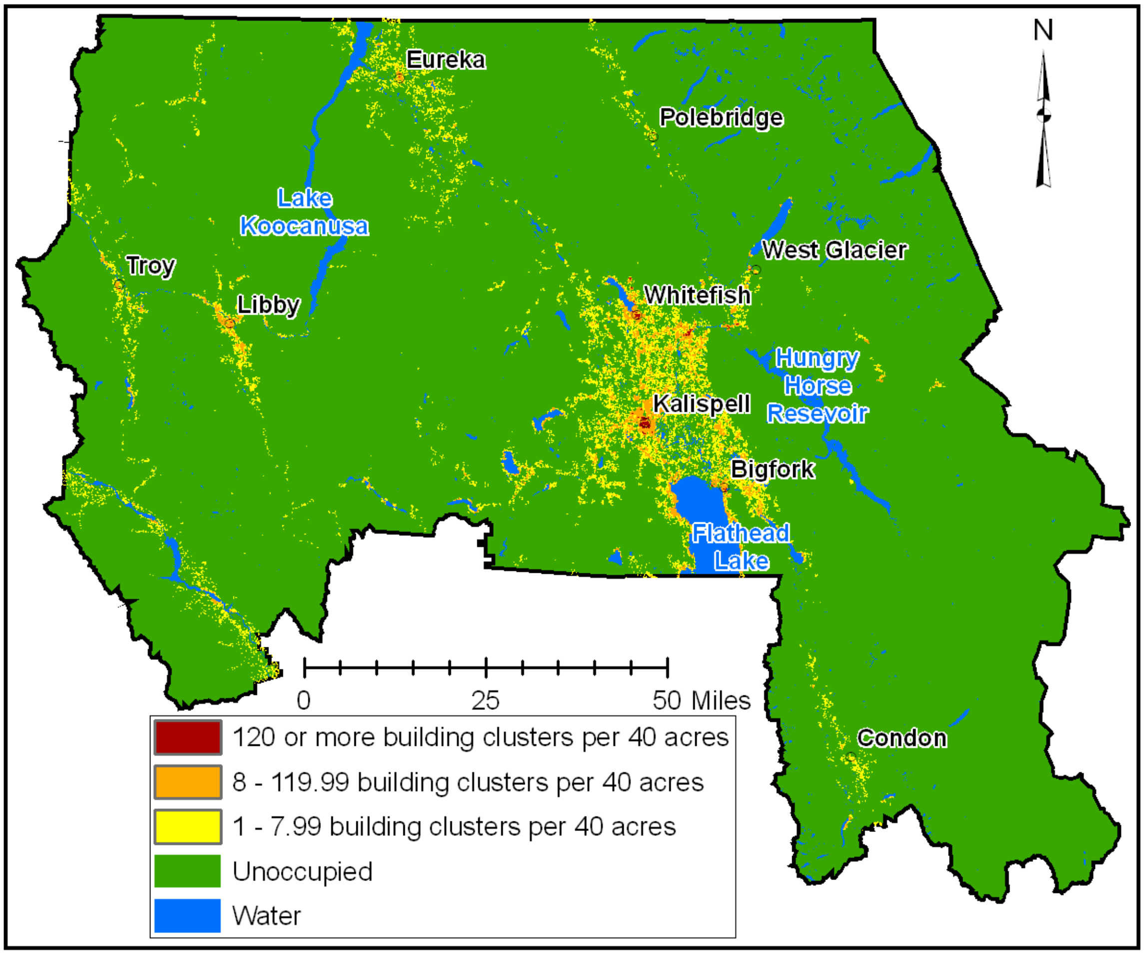


Figure 4. Northwest Montana FPU cadastral Building Clusters density.

Structure value alone does not indicate the number of structures actually located on the parcel; it simply indicates that one or more buildings are present within the boundaries of the corresponding land parcel that have a total value amounting to the structure value. Since each point could potentially represent more than one structure, the centroid points are called ‘Building Clusters.’ Given that each building cluster point is located at the geographic center of the parcel it represents, the larger the parcel of land each point is situated upon, the greater the probability that the building cluster is not proximate to actual structures, increasing the likelihood of error. However, the building clusters are not intended for use as a tactical tool for on-the-ground deployment of scare suppression resources, where local knowledge should supersede the often-dated cadastral data. Nonetheless, cadastral data have been demonstrated to be an appropriate building-location proxy for strategic fire management and have been shown to be useful in prioritizing fires for assignment of scarce suppression resources within the area command setting (FGDC - CDS, 2007; RMRS, 2008b). Further research found that building clusters identify parcels where one or more GPS structures are present with 90% accuracy in Gallatin County, Montana (Calkin, et al., in review).

Oak Ridge National Laboratory: LandScan

LandScan was developed by the DOE's ORNL Global Population Project, with funding from the DOD, for estimating the number of people at risk from various anticipated anthropogenic and natural disasters (Bhaduri, et al., 2002). The database was derived from the best available Census counts that were redistributed to spatial cells from probability coefficients related to slope, road proximity, land cover, nighttime lights, and other information including an urban density factor (Dobson, et al., 2000). The LandScan Dataset files are available in raster format via the internet in an aggregated format generalized for public consumption, approximately a 1 km × 1 km grid projected in latitude/longitude coordinates. LandScan USA is a project extension producing a very high-resolution (~90 m × 90 m) population distribution database for the United States that predicts with high accuracy how many people are present in any given area during the night (also known as residential population), as well as the day (Krause, 2002). This analysis will use the highest resolution dataset (which will be referred to hereafter as LandScan, dropping the 'USA' for simplicity), provided by Nagendra Singh and Budhendra Bhaduri (2008) of the ORNL. This dataset was then manipulated and classified (based on the USDA and DOI (2001b: 753) schema for population density located within the Federal Register) to align and conform to the other data files used in this study (Figure 5). LandScan datasets are released annually, with each new release superseding the previous (not considered an update); new releases cannot be compared to previous datasets for the purpose of tracking change. The reason that these data should not be utilized as a change detection or migration tool lies in the fact that the input datasets used to perform the LandScan analysis are constantly improving, which in turn changes the population distribution without any actual 'migrations' taking place (ORNL, 2008).

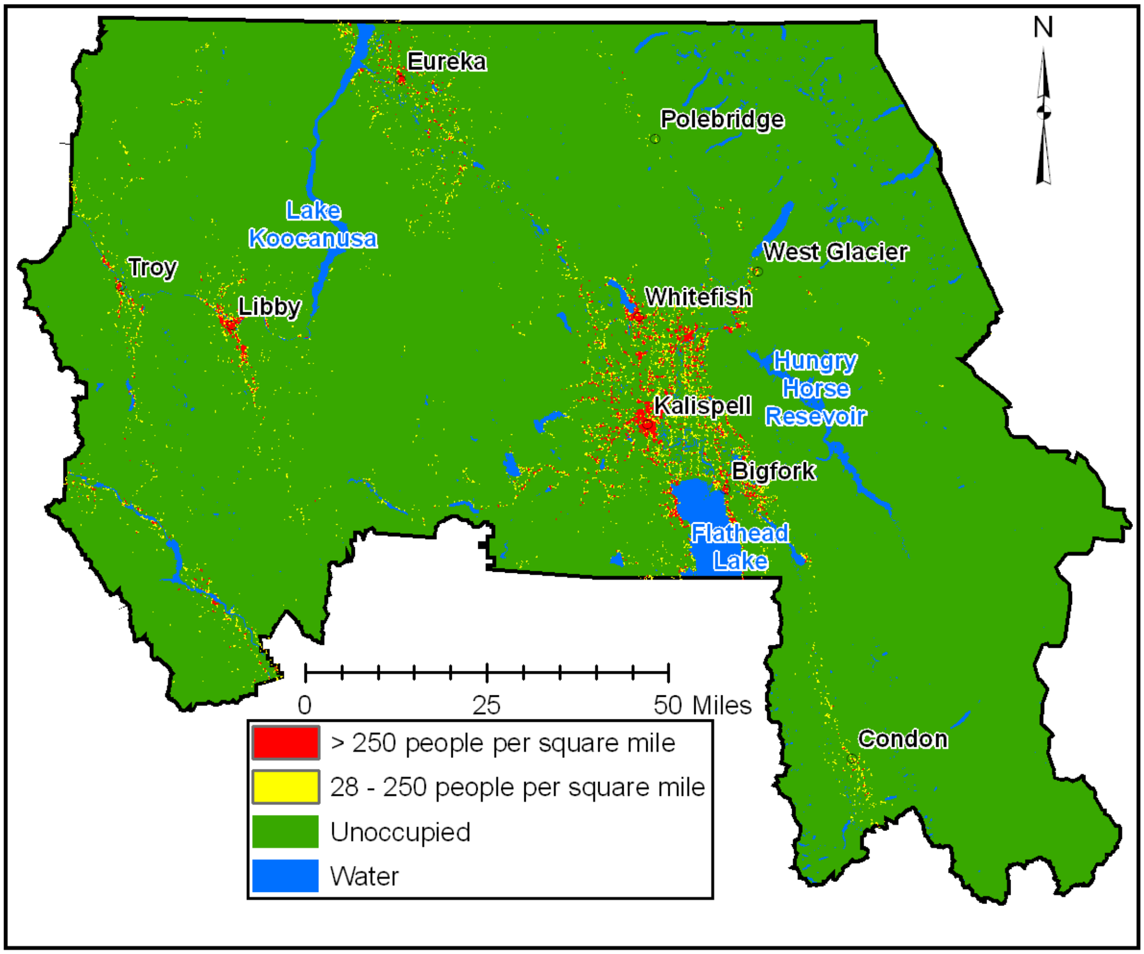


Figure 5. Northwest Montana FPU LandScan population estimate.

LandScan data are routinely being used with counter-terrorism, homeland security, emergency planning and management (rapid risk and disaster assessment, evacuation planning, relief delivery, etc.), consequence analysis, public health (epidemiology, exposure analysis, facility access, etc.), exposure analysis, and urban sprawl detection to estimate the number of people at risk from various anticipated disasters (Bhaduri, et al., 2002; Krause, 2002; Bhaduri, et al., 2007; Bhaduri, 2008). The ORNL have distributed LandScan data to over

200 different national and international organizations around the world including, the United Nations (UN), the UN's World Health Organization, the UN's Food and Agricultural Organization, and several federal agencies in the US and other countries (Dobson, et al., 2000; Bhaduri, et al., 2002).

LandScan values do not represent structures; the distribution represents "ambient population" (average population distribution) which integrates diurnal movements and collective travel habits into a single measure and does not attempt to distinguish the timing of such movements beyond daytime and nighttime (Dobson, et al., 2000). As mentioned previously, the U.S. Census provides the basis for the nighttime (residential) LandScan product providing the number of people who live and sleep in each home in a city block (Krause, 2002). Locating daytime populations requires not only Census data, but also other socio-economic data including places of work, journey to work, and other mobility factors. The combination of both residential and daytime populations provides significant enhancements to geospatial applications ranging from homeland security to socio-environmental studies, including, but not limited to: emergency planning and management, rapid risk assessment, evacuation planning, consequence assessment, and mitigation planning and implementation (ORNL, 2005). Although LandScan does not attempt to represent structure location, a strong positive correlation is expected to exist between where people are and where structures are located. Additionally, the LandScan variable inputs incorporate WUI Risk Factor criteria[3] defined by the Federal Register such as transportation networks, slope, and land cover, potentially providing greater insight towards characteristics of the WUI than structure location alone.

SILVIS Laboratory at the University of Wisconsin-Madison

The objective of the People and Houses Research Project investigating the Wildland-Urban Interface in the United States at the Forest and Ecology

[3] See Appendix: Preliminary Criteria for Evaluating Risk to Communities, Risk Factors 1, 2, and 3.

Laboratory at the University of Wisconsin is to conduct a spatially detailed national assessment of the WUI across the conterminous US to support inquiries into the effects of housing growth on the environment, and to inform both national policy and local land management concerning the WUI and associated issues (Radeloff, et al., 2005). This laboratory derives its name, SILVIS, "from its mission to provide spatial analysis for conservation and sustainability" (Hinterhuer, 2008). As discussed previously, SILVIS (2008) defines the WUI as the area where houses meet wildland vegetation (i.e., interface WUI), or where houses and vegetation are mixed together (i.e., intermix WUI). Following the parameters set forth in this WUI definition, necessary inputs for studying the WUI include housing and vegetation data.

In conducting their assessment identifying the WUI, the researchers at the SILVIS Lab compares two datasets (Radeloff, et al., 2005), US Census housing data and the USGS National Land Cover Dataset (NLCD). The Census data permit the calculation of housing units (structures) count per Census block. These values are then divided by the acreage of the corresponding Census block creating a density ratio of structures per unit area. The national standard defining the WUI set forth in the Federal Register (USDA and DOI, 2001b) indicates a minimum of 1 structure per 40 acres; areas with less structure density are categorized as 'Non-WUI: Very Low Density' or 'Non-WUI: No Housing,' as appropriate (Radeloff, et al., 2005).

The NLCD vegetation data are reclassified by retaining wildland vegetation while excluding other vegetation types; Stewart et al. (2007: 203) describe the categorization process of "'wildland vegetation' as all types of vegetative cover except those that are clearly not wild, such as urban grass, orchards, and agricultural vegetation". Further clarification by Radeloff et al. (2005: 800) defines 'wildland vegetation' as the following land cover classes: coniferous forest, deciduous forest, mixed forest, shrubland, grasslands/herbaceous, transitional, and woody and emergent herbaceous wetlands; excluded from the 'wildland vegetation' classification scheme were low- and high-intensity residential, commercial/industrial, orchards/vineyards, pasture/hay, row crops, small grains, fallow, urban/recreational grasses, bare rock/sand/clay, quarries, open water, and perennial ice/snow. Upon reclassification of the vegetation data, the percentage of wildland vegetation is then calculated for each Census block.

Locations (i.e., Census blocks) containing a minimum density of 1 structure per 40 acres that were also characterized with wildland vegetation covering 50% or more of the terrestrial area of a given Census block are classified as WUI Intermix. Regions with a minimum density of 1 structure per 40 acres, and which contained less than 50% wildland vegetation but which were located within 1.5 miles (2.4 km) of an area that is heavily vegetated (>75% wildland vegetation), and which was larger than 1325 acres (500 ha) were categorized as WUI Interface. The Healthy Forests Restoration Act of 2003 states that an area within 1.5 miles of the boundary of an at-risk community can be considered within the WUI (Public Law 108-148, 2003); this distance represents an estimate of the distance a firebrand can fly ahead of a fire front, possibly creating spot fires (Radeloff, et al., 2005). The minimum-size threshold of 1325 acres for areas that are heavily vegetated was set to avoid including residential areas that are within 1.5 miles of small urban parks. Remaining areas were then classified as either water or non-vegetated. Each category is further subdivided into regions by density (very low density: < 1 structure per 40 acres; low density: ≥ 1 structure per 40 acres and < 8 structures per 40 acres; medium density: ≥ 8 structures per 40 acres and < 120 structures per 40 acres; high density: ≥ 120 structures per 40 acres). The threshold between the very low density and low density classes (i.e., 1 structure per 40 acres), and that between the medium and high density classes (3 structures per acre), are derived directly from the USDA and DOI and are located within the Federal Register (USDA and DOI, 2001b: 753). Figure 6 depicts the criteria employed by the SILVIS Lab to define the extent of the WUI.

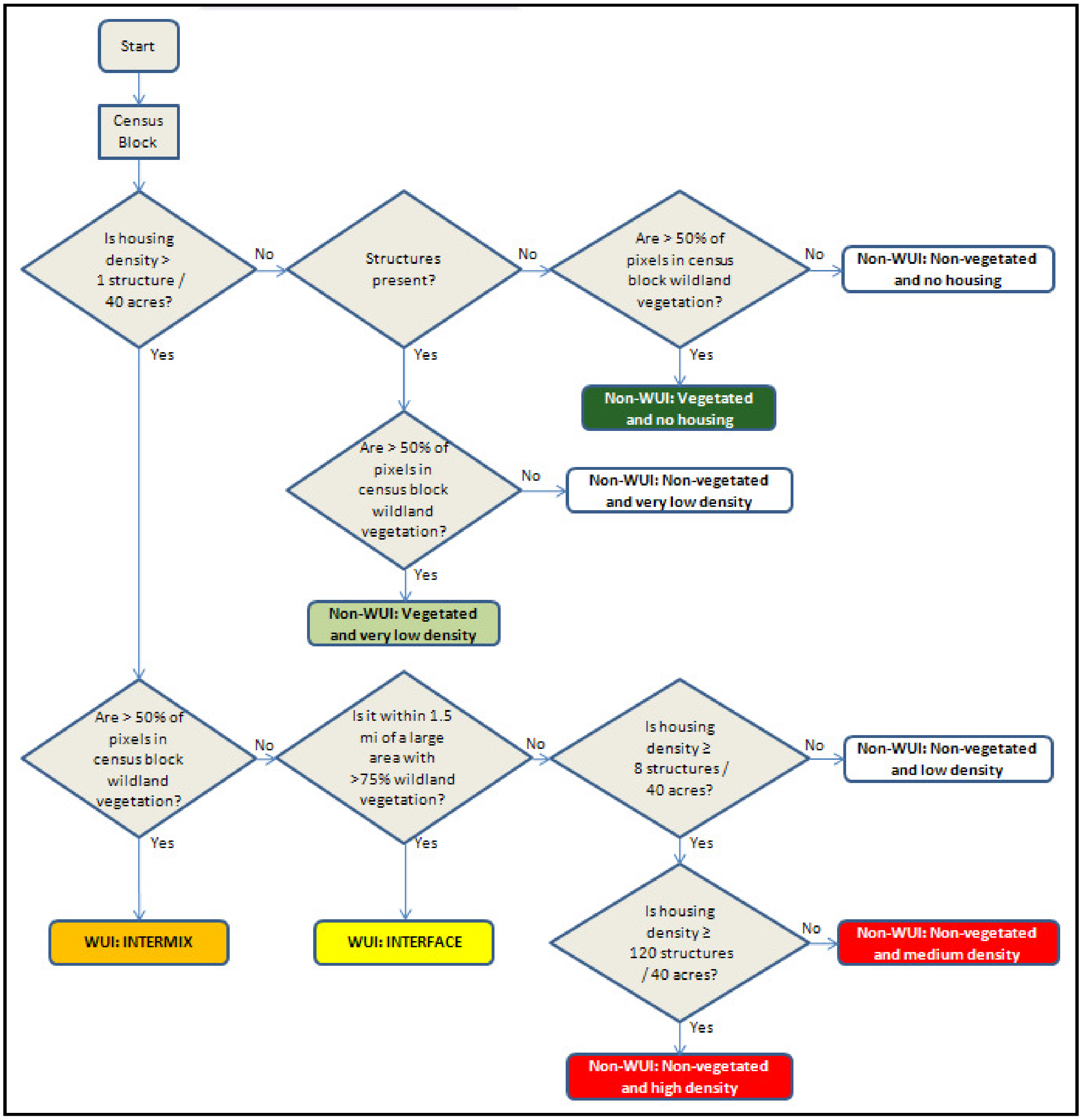


Figure 6. SILVIS Lab WUI definition flowchart, adapted from Stewart et al. (2007).

The analysis performed by the SILVIS Lab covers the contiguous (lower 48) United States; these results must be obtained individually, by state. The maps for both Montana and Idaho were acquired and clipped to the boundary of the Northwest Montana FPU (Figure 7). The SILVIS Lab's maps are intended to illustrate where the WUI was located in the year 2000.

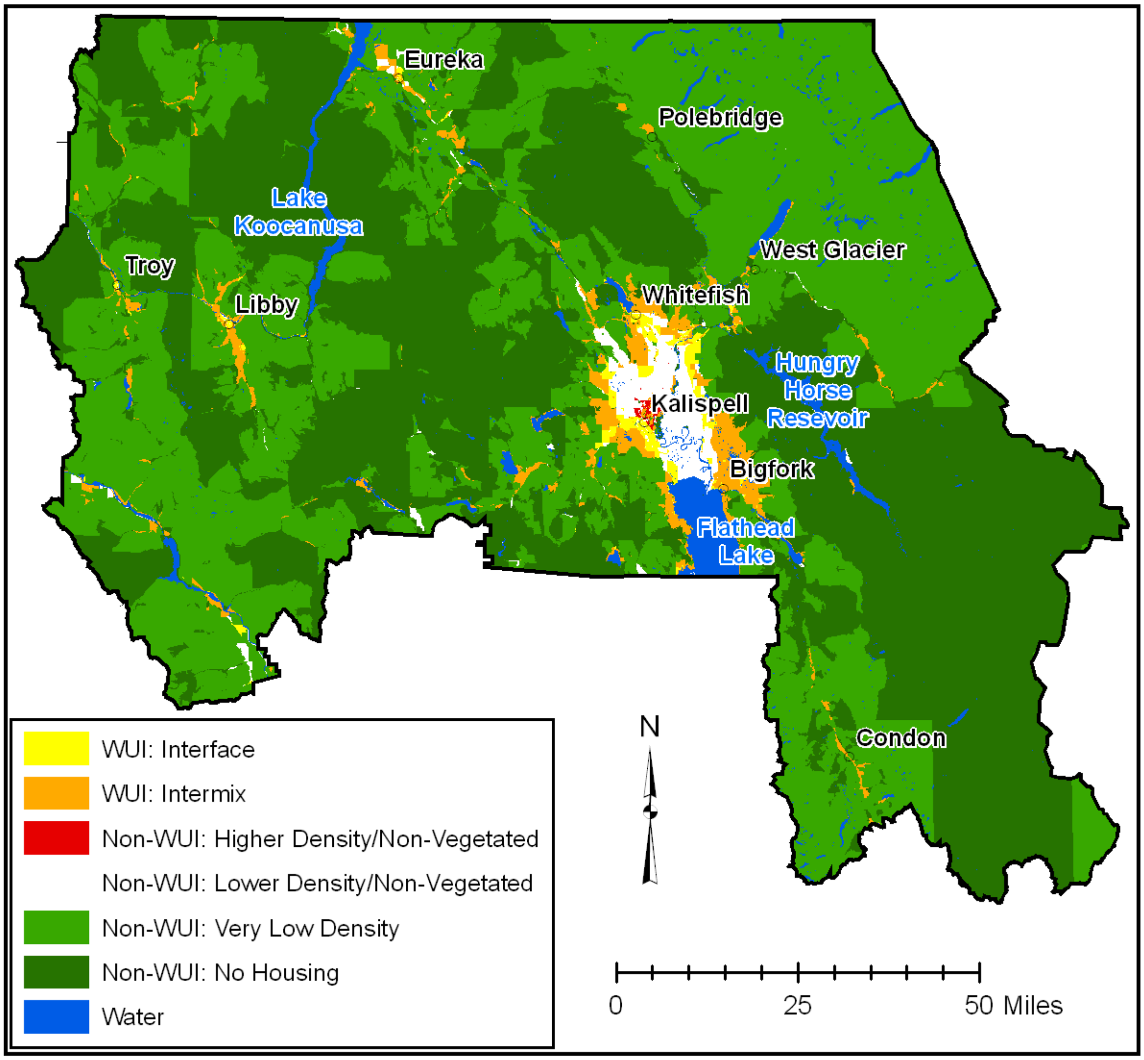


Figure 7. Northwest Montana FPU SILVIS Wildland-Urban Interface defined.

3. Data Preparation

Once compiled, all datasets required processing to create a uniform configuration permitting comparisons between the various datasets to observe what relationships exist. Each dataset must have identical geographic coordinate systems including the same datum, projection, and raster cell-size while assuring each cell aligns with the corresponding cells of other datasets to allow cell-by-cell analysis. The North American Datum of 1983, with an Albers equal-area conic projection (NAD83-Albers), was chosen because the national FPA burn probability grid, which includes the Northwest Montana FPU prototype area, employs this geographic reference system with every grid cell representing 270 m × 270 m (Finney, 2007). Conforming all of the data to match the FPA output allows for further risk assessment research beyond the parameters of this study without the need for additional data processing.

The cadastral building clusters vector data needed conversion from a point shapefile into a raster format aligning with all other datasets. The building clusters data were overlain by the FPA 270 m × 270 m equal-area grid (described above that will be utilized to perform all analyses in this study) to calculate the number of building clusters per grid cell. Special care was adhered to ensuring that cells with zero building clusters were assigned the value of zero, not 'NoData' (many raster analysis techniques ignore cells with a value of 'NoData' and/or differentiate between 'NoData' and zero or nulled data). The data were then reclassified into high, medium, and low density cells employing the same specifications established in the Federal Register and refined by the SILVIS Laboratory: low WUI density of 1 to 7.999 structures per 40 acres; medium WUI density of 8 to 119.999 structures per 40 acres; and high WUI density of 120 or more structures per 40 acres.

An agreement with LandScan USA allowed the acquisition of the fine-scale raster datasets (approximately 90 m × 90 m) in the World Geodetic System of 1984 (WGS84), which is not an equal-area projection (each cell does not necessarily represent the same amount of land area ─ area varies by latitude). The WGS84 coordinate system is based on degrees of latitude and longitude. Lines of latitude, also known as parallels, are spaced evenly, with each degree of latitude approximately 69 miles (DOI, 2009). However, lines of longitude are approximately 69 miles apart at the equator (0°) and converge at the poles (90°); therefore, east-west distances are largest at the equator and decrease in size towards the poles with a degree of longitude approximately 49 miles in width at 45 degrees North and South latitude (DOI, 2009). If one were to envision latitude and longitude as a grid; each cell within any given row will have the same area, whereas each cell within a column comprises different areas, with larger areas occurring closer to the equator. Since individual cells are of different size, each cell represents population count; population density requires normalization of cell size (each cell must be of equal area). Therefore, the LandScan data must undergo a transformation to conform to the NAD83-Albers projection of the FPA burn probability dataset to represent population density per 270 m × 270 m cell (approximately 18 acres).

The transformation of the LandScan data involved converting the raster data into a point shapefile, changing the projection of the point shapefile from WGS84 to the NAD83-Albers projection, and finally summing the population estimates located within the 270 m × 270 m FPA burn probability grid. This method was employed to reduce the smoothing and edge effects that would have caused data loss if simple raster resampling had been instead performed. The best raster resampling technique employed on this data caused 50 million people, or $^{1}/_{6}$ of the population of the United States, to disappear; obviously an unacceptable difference in population count. The transformation method used in this study retains all 297,442,933 people counted in the original LandScan USA 2006 dataset.

Once the LandScan dataset were converted to represent population density, the data underwent reclassification to match the population density schema set forth by the USDA and DOI (2001b:753) and found within the Federal Register: ≥ 250 people per square mile (>7 people per 270 m × 270 m cell) as interface (corresponding to high structure density), and 28-250 people per square mile (1-7 people per 270 m × 270 m cell) as intermix (corresponding to the combined low and medium structure density categories). The LandScan population data cannot be classified to distinguish between low and medium density in a meaningful and comparable manner. As mentioned earlier, the USDA and DOI (2001b) created their interface and intermix structure density thresholds based on *The Wildland/Urban Interface Fire Problem* report to the council of Western State Foresters (Teie and Weatherford, 2000) while including additional criteria for population density. The SILVIS Lab subdivided that intermix classification into low and medium structure densities, determining that threshold at 8 structures per 40 acres; no other literature subdivides the intermix classification. With no known direct correlation between structure density and population density, the intermix population density category cannot be subdivided with criteria congruent to the low and medium housing density schema. Nonetheless, one can compare interface and intermix (by not subdividing this category into low and medium classes) since the USDA and DOI (2001b) include interface/intermix criteria for both structure density and population density employing a three-class schema (interface, intermix, and unoccupied).

The SILVIS data also underwent conversion from vector to raster format, ensuring grid alignment with the FPA, LandScan, and building clusters raster grids. By overlaying the SILVIS polygon vector data with a null raster grid, the value of each cell was determined, analyzing cell by cell, by assigning the classification schema that dominated the respective cell (Maximum-Combined-Area cell assignment type). After transforming the SILVIS data into a raster format that aligns with the other datasets, the SILVIS data also underwent reclassification sorting the data into structure density categories regardless of WUI designation (eliminating the dependence on vegetation, creating a classification schema dependant entirely on structure density); thus permitting comparisons to the LandScan and cadastral data (which are classified purely on density levels, no vegetation characteristics are taken into consideration at this time). Moreover, question one asks how well *all* structure locations are estimated, not just structures within the WUI. Creating a uniform configuration with aligned datasets resulting in the maps found in Figure 8, permits a cell-by-cell analysis.

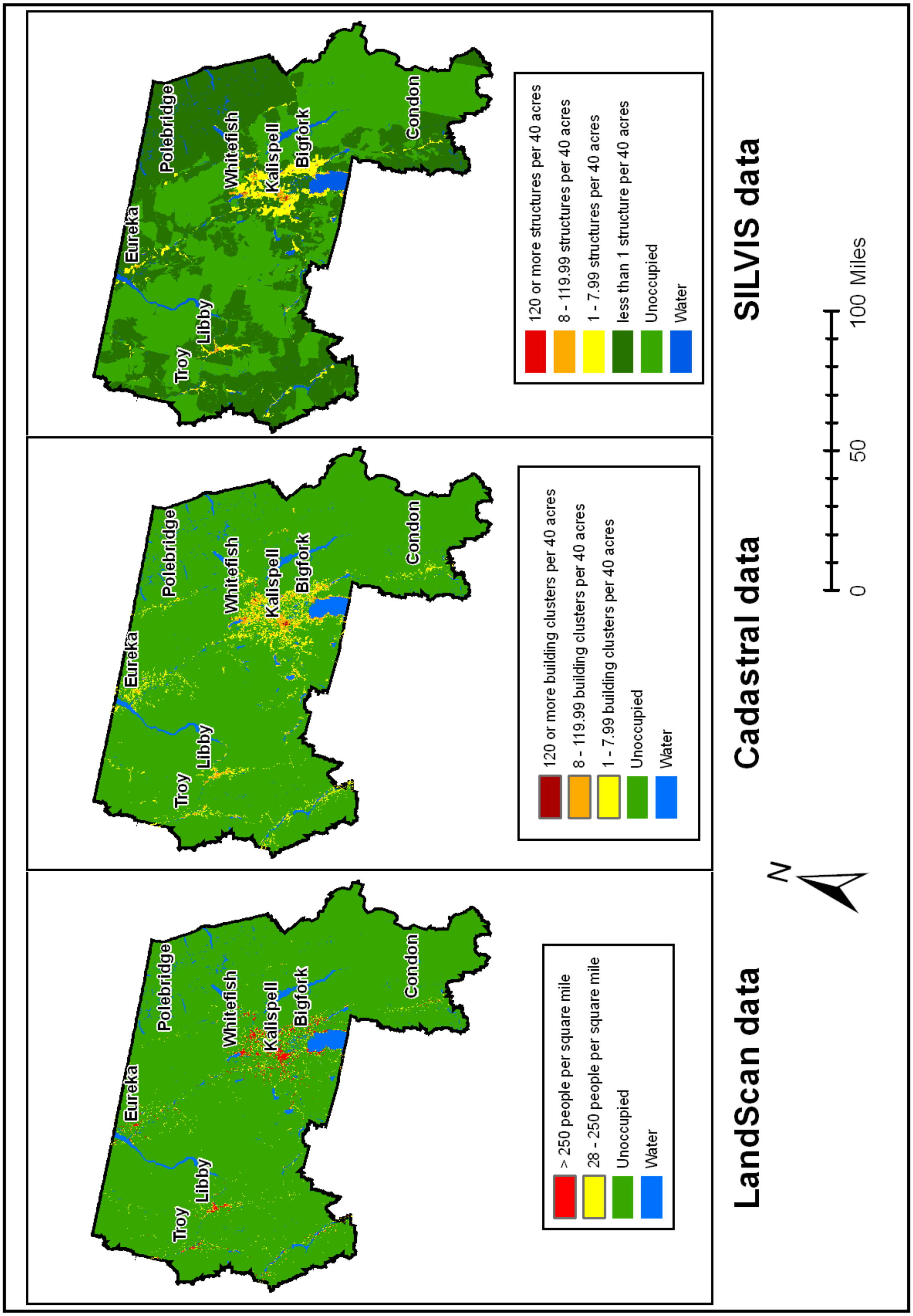


Figure 8. Comparison of Prepared Datasets - LandScan, Cadastral, and SILVIS.

Question Two set out to examine the WUI; the Healthy Forests Restoration Act of 2003 (Public Law 108-148) defines the WUI as an area within 1½-miles of a community. Therefore, the cadastral building clusters, LandScan, and SILVIS datasets underwent buffering, on a cell by cell basis (at 270 m intervals), out to 1½-miles (2.4 km) from all WUI values (structures for cadastral and SILVIS data; and population density counts for LandScan data).

At this juncture, all three datasets were converted to raster format, aligned, buffered, and prepared for analysis by clipping the extent of the data to the boundaries of the NWMT FPU.

4. Analytical Procedure

Both the SILVIS data and LandScan data were compared to the cadastral data by overlaying the respective, aligned, raster grids and evaluating the class of each raster cell within the study area, cell-by-cell, to determine the spatial coincidence between the datasets. Neither the SILVIS data nor the LandScan data represent truth; therefore, they were not compared to each other directly. The results were tabulated utilizing error matrices (also known as a contingency tables or confusion matrices).

The degree of spatial coincidence between the datasets was measured employing the Kappa Index of Agreement (KIA), which is also known as Cohen's Kappa Coefficient of Agreement; a statistical measure of agreement for mutually exclusive (each individual cell must be classified as belonging to only one category, no fuzzy classification) categorical data rendering values between 0 and 1 (Table 1), with greater agreement represented by KIA values closer to 1 (Landis and Koch, 1977; Rosenfield and Fitzpatrick-Lins, 1986; Congalton, 1991; Fielding and Bell, 1997; Pontius, 2000; Barreto-Neto and Barras da Silva, 2004). The KIA values were calculated employing the Idrisi32 computer program (Eastman, 2000).

Table 1. Kappa Index of Agreement rankings.

Landis & Koch (1977)		Jensen (2004)			
81 % - 100 %	almost perfect	> 80 %	strong agreement		
61 % - 80 %	substantial	40 - 80 %	moderate agreement	Thesis Synthesis	
41 % - 60 %	moderate	< 40 %	poor agreement	> 85 %	excellent
21 % - 40 %	fair			70 - 85 %	very good
0 - 20 %	slight			60 - 70 %	good
< 0 %	No agreement	Barreto-Neto & Barcas da Silva (2004)		45 - 60 %	moderate
		80 % - 100 %	excellent	35 - 45 %	fair
Fielding & Bell (1997)		61 % - 80 %	very good	25 - 35 %	poor
> 75 %	excellent	41 % - 60 %	good	< 25 %	extremely poor
40 - 75 %	good	21 % - 40 %	reasonable		
< 40 %	poor	0 - 20 %	bad		

The KIA is a measure of agreement based on the difference between the actual agreement in the error matrix and chance agreement (Congalton and Green, 2009). The Kappa statistic is defined as:

$$\hat{K} = \frac{p_o - p_e}{1 - p_e} \tag{1}$$

where p_o is observed proportion correct, and p_e is the expected proportion correct due to chance.

Table 2. Statistics calculation example.

		Coin 1	
		Heads	Tails
Coin 2	Heads	35	30
	Tails	15	20

Demonstrating how the KIA is calculated aids in understanding of the Kappa statistic. Suppose one were analyzing data related to simultaneous coin flipping. Two coins are tossed into the air and the results, either heads or tails, are calculated for each with the results in Table 2. Note that each coin was flipped 100 times; 35 times, both coins were heads; 20 times, both coins landed tails-up. Thus the observed percentage agreement is $p_o = (35 + 20) / 100 = 0.55$. To calculate the probability of random agreement (p_e): Coin 1 landed heads-up

50 times and tails-up on 50 occasions; thus coin 1 landed heads-up 50% of the time and tails-up 50% of the time. Coin 2 landed heads-up 65 times and tails-up 35 times; thus coin 2 landed heads-up 65% of the time and tails-up 35% of the time. Therefore, the probability that both of them would land heads-up is $0.50 \times 0.65 = 0.325$ and the probability that both coins would land tails-up is $0.50 \times 0.35 = 0.175$. Thus the overall probability of random agreement is $p_e = 0.325 + 0.175 = 0.50$. Substituting the above values into the formula for Cohen's Kappa yields the following computations:

$$\hat{K} = \frac{p_o - p_e}{1 - p_e} = \frac{0.60 - 0.50}{1 - 0.50} = 0.20 \qquad (2)$$

The KIA value of 0.20 represents a poor to very poor level of agreement indicating that the results of flipping coin 1 one hundred times is a poor to very poor predictor of the simultaneous results of flipping coin 2 one hundred times. Although this example has an overall accuracy of 55%, the KIA of 0.20 suggests that most of that agreement occurs by chance.

In addition to the Kappa statistic, error matrices allow the computation of map accuracy. As Jensen (2005: 506) notes:

> Sometimes we are producers of classification maps and sometimes we are users. Therefore, we should always report all three accuracy measures: overall accuracy, producer's accuracy, and user's accuracy, because we never know how the classification will be used.

The overall accuracy is determined by dividing the total correct pixels (shaded gray) by the total number of pixels in the error matrix. Producer's accuracy and user's accuracy are ways of representing individual category accuracies and were introduced to the remote sensing community by Story and Congalton (1986). User's accuracy, also known as "reliability," (Story and Congalton, 1986: 398) is the probability that a pixel classified on the map actually represents that category on the ground. The producer's accuracy value has an inverse relationship with errors of omission and sum to 100%; if the producer's accuracy is 75%, then the omission error is 25%. Analogously, the user's accuracy value has an inverse relationship with errors of commission, which also sum to 100%. A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs. Also, each error is both an omission from the correct category and a commission to a wrong category. Calculating these values with Table 1 (although not a map, the values are computed from map-derived error matrices in the same manner) reveals the following results:

- the overall accuracy is (35 + 20) / (35 + 30 + 15 + 20) = 55 / 100 = 55%;
- the user's accuracy for 'Heads' is 35 / (35 + 30) = 35 / 65 = 53.8%, and the 'Heads' commission error equals 30 / (35 + 30) = 30 / 65 = 46.2%;
- the user's accuracy for 'Tails' is 20 / (15 + 20) = 20 / 35 = 57.1%, and the 'Tails' commission error is 15 / (15 + 20) = 15 / 35 = 42.9%;
- the producer's accuracy for 'Heads' is 35 / (35 + 15) = 35 / 50 = 70%; and the 'Heads' omission error is 15 / (35 + 15) = 15 / 50 = 30%;
- the producer's accuracy for 'Tails' is 30 / (30 + 20) = 30 / 50 = 60%; and the 'Tails' omission error is 20 / (30 + 20) = 20 / 50 = 40%.

IV. RESULTS AND DISCUSSION

The first question posed in this research pertains to structure location. The LandScan data was overlaid with the cadastral data to measure, on a cell-by-cell basis, the level of spatial coincidence between them. Additionally, since the SILVIS dataset is an already accepted standard, currently in use by the FPA in their fire management and planning, the level of spatial coincidence between the SILVIS data and the cadastral data was measured allowing comparisons to the LandScan/cadastral results. Not only will this allow for comparisons between the two predictive datasets (LandScan and SILVIS), but provide an opportunity to assess the accuracy of these datasets; this becomes increasingly important as the datasets age (Census-block derived datasets rely on data generated every 10 years; both the SILVIS data, and to a lesser extent, the LandScan data employ Census-block data).

The second question posed in this research evaluates the ability of LandScan data to be utilized as a basis to predict the location of the WUI. Akin to the first spatial analysis, the buffered cadastral building clusters data will be compared, on a cell-by-cell basis, to both the buffered SILVIS data and buffered LandScan data via an error matrix calculating the KIA. Once again, the level of spatial coincidence between the SILVIS dataset and the cadastral dataset was performed to permit comparisons with a widely accepted Census block-level method. Additionally, since the FPA employs a buffered SILVIS WUI for its fire management planning and activities, assessing the SILVIS data is justified following federal guidelines ensuring the use of the best available science and that it is the research community's responsibility to make those available (USDA and DOI, 2009).

This study will conclude with a discussion of the advantages and disadvantages of each WUI map product with recommendations for further research based on these results.

1. Question 1: Locating Structures

The error matrix table construction and Kappa Index of Agreement calculation can take several forms. Both the cadastral and SILVIS datasets can be classified into four housing density classes using the schema developed by the SILVIS lab: unoccupied (< 1 structure per forty acres), low density (1-7.999 structures per forty acres), medium density (8-119.999 structures per forty acres), and high density (120+ structures per forty acres). However, the LandScan data was classified employing population density rather than structure density and conforms to only three clearly defined categories of the USDA and DOI (2001b: 753) and found in the Federal Register: unoccupied, intermix (low and medium density), and interface (high density). In addition, an occupied/unoccupied binary error matrix can be computed for all datasets.

Table 3. SILVIS - Cadastral 4 Classes Structural Error Matrix and KIA.

		Cadastral: Reference Image							
		Unoccupied	Low Den.	Med. Den.	High Den.	Total	Err. of Comm.	User's Acc.	KIA
SILVIS: Mapped	Unoccupied	388,749	8,092	967	6	397,814	2%	98%	0.45
	Low Density	5,453	4,616	1,794	10	11,873	61%	39%	0.37
	Medium Density	153	289	1,071	57	1,570	32%	68%	0.68
	High Density	0	1	18	54	73	26%	74%	0.74
	Total	394,355	12,998	3,850	127	411,330			
	Error of Ommision	1%	64%	72%	57%		4%		
	Producer's Accuracy	99%	36%	28%	43%			96%	
	Categorical Kappa	0.57	0.34	0.28	0.43			overall Kappa:	0.43

Table 3 displays a four class error matrix measuring spatial coincidence between the SILVIS and cadastral datasets. Due to the large number of unoccupied cells within the study area, the overall level of accuracy is 96%. Yet, the overall Kappa Index of Agreement is 0.43, a fair level of spatial coincidence (the precise method for calculating this overall KIA is described in Congalton and Green, 2009: 113).

In areas with medium to high housing density, where smaller Census blocks are common, the SILVIS dataset retains good to very good spatial coincidence as indicated by higher categorical KIA (0.68 and 0.74) values than the overall KIA.

However, the SILVIS based low density categorical KIA (0.37) value is lower than the overall KIA; in addition, the user's accuracy for low density is dramatically lower than all other categorical user's accuracy levels. As discussed earlier, this may occur due to the SILVIS dataset's reliance on Census block-level data, designating all pixels within those blocks with a homogeneous class assignment. Whereas, on the ground, low density Census blocks tend to be comprised with a less uniform settlement pattern and also tend to be larger in size causing larger spatial coincidence errors. Supporting evidence of the smoothing effect of designating an entire Census block the same classification is revealed in low Producer's Accuracies (low density: 36%; medium density: 28%; high density: 43%). Further evidence of this trend arises when analyzing the cadastral categorical KIA values; the unoccupied value (0.57) is higher than the overall KIA and the populated KIA values (0.34; 0.28; 0.43) are slightly lower than the overall Kappa.

Table 4. SILVIS - Cadastral 3 Classes Structural Error Matrix and KIA.

SILVIS: Mapped	Cadastral: Reference Image							
		Unoccupied	Intermix	Interface	Total	Err. of Comm.	User's Acc.	KIA
	Unoccupied	388,749	9,059	6	397,814	2%	98%	0.45
	Intermix	5,606	7,770	67	13,443	42%	58%	0.56
	Interface	0	19	54	73	26%	74%	0.74
	Total	394,355	16,848	127	411,330			
	Error of Ommision	1%	54%	57%		4%		
	Producer's Accuracy	99%	46%	43%			96%	
	Categorical Kappa	0.57	0.44	0.43			overall Kappa:	0.50

Combining the low and medium density categories creates three WUI classes based on the schema found in the Federal Register (low and medium density = Intermix; high density = Interface). Table 4 displays the spatial coincidence between the SILVIS and cadastral datasets employing 3 classes. The Intermix category improves the categorical KIA (0.56) and accuracy levels (compared to the separated low and medium density classes) yet their relative value to the overall Kappa (0.50) remains approximately the same; also, the cadastral categorical Intermix (0.44) and Interface (0.43) KIA values remain below the overall KIA value, indicating that although the SILVIS data predictions have moderate spatial coincidence with the Cadastral data, the SILVIS data underestimates the amount it should be predicting (with fair spatial coincidence). This is reflected when analyzing the number of pixels classified as occupied (either Intermix or Interface): the Cadastral data reveals that 16,975 cells contain structures and the SILVIS data identifies only 13,516 pixels with structures.

Table 5. LandScan - Cadastral 3 Classes Structural Error Matrix and KIA.

		Cadastral: Reference Image						
		Unoccupied	Intermix	Interface	Total	Err. of Comm.	User's Acc.	KIA
LandScan: Mapped	Unoccupied	391,525	11,778	11	403,314	3%	97%	0.29
	Intermix	2,314	2,570	2	4,886	47%	53%	0.51
	Interface	516	2,500	114	3,130	96%	4%	0.04
	Total	394,355	16,848	127	411,330			
	Error of Ommision	1%	85%	10%		4%		
	Producer's Accuracy	99%	15%	90%			96%	
	Categorical Kappa	0.63	0.14	0.90			overall Kappa:	0.30

Table 5 depicts the spatial coincidence between the LandScan and cadastral datasets following the classification guidelines for population density set forth in the Federal Register. When using the LandScan image as the reference, each category performs worse than the respective SILVIS category, with only the Intermix category scoring close to the SILVIS results (0.45 > 0.29; 0.56 > 0.51; 0.74 > 0.04). When referring to the cadastral dataset as the reference image, it may appear that the Interface values of the LandScan data are high, but when one takes into account the extremely low user's accuracy, the high producer's accuracy value is diminished to the point of insignificance. Another way to consider this point is that although 90% of pixels identified as Interface by the Cadastral data are correctly identified as Interface by the LandScan data, only 4% of the LandScan Interface designated cells are actually Interface locations. In addition, the overall KIA is significantly lower for the LandScan data (0.30), implying that SILVIS data (0.50) more accurately predicts the location of structures; however, this prediction capability is only moderate.

Table 6 SILVIS - Cadastral 2 Classes Structural Error Matrix and KIA.

		Cadastral: Reference Image					
		Unoccupied	Occupied	Total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Unoccupied	388,749	9,065	397,814	2%	98%	0.45
	Occupied	5,606	7,910	13,516	41%	59%	0.57
	Total	394,355	16,975	411,330			
	Error of Ommision	1%	53%		4%		
	Producer's Accuracy	99%	47%			96%	
	Categorical Kappa	0.57	0.45			overall Kappa:	0.50

The third method to evaluate spatial coincidence between these datasets rests with a binary analysis. Table 6 displays the binary error matrix produced comparing the SILVIS data to the cadastral data. This table is very similar to the error matrix produced analyzing the SILVIS data with the three categories defined in the Federal Register; the improvement of the overall Kappa value is so slight it vanishes with rounding.

Table 7 LandScan - Cadastral 2 Classes Structural Error Matrix and KIA.

		Cadastral: Reference Image					
		Unoccupied	Occupied	Total	Error of Commision	User's Accuracy	KIA
LandScan: Mapped	Unoccupied	391,525	11,789	403,314	3%	97%	0.29
	Occupied	2,830	5,186	8,016	35%	65%	0.63
	Total	394,355	16,975	411,330			
	Error of Ommision	1%	69%		4%		
	Producer's Accuracy	99%	31%			96%	
	Categorical Kappa	0.63	0.29			overall Kappa:	0.40

However, when the LandScan data are evaluated in a binary format, as depicted in Table 7, the values improve dramatically over the three classes LandScan values; nonetheless, the LandScan to cadastral overall KIA (0.40) remains much lower than the corresponding SILVIS to cadastral value (0.50). Note that the LandScan data only predicts 8,016 cells as occupied whereas the Cadastral data indicates that 16,975 pixels are occupied (47%).

Table 8 SILVIS - Cadastral 2 Classes Structural Error Matrix and KIA with Very Low as Occupied.

SILVIS: Mapped	Cadastral: Reference Image						
		Unoccupied	Occupied	Total	Error of Commision	User's Accuracy	KIA
	Unoccupied	202,157	1,384	203,541	1%	99%	0.84
	Occupied	192,198	15,591	207,789	92%	8%	0.04
	Total	394,355	16,975	411,330			
	Error of Ommision	49%	8%		47%		
	Producer's Accuracy	51%	92%			53%	
	Categorical Kappa	0.04	0.84			overall Kappa:	0.07

To ensure no classification schema was overlooked, one final binary error matrix was constructed by classifying Census blocks with the SILVIS lab designation of 'Very Low Density' as occupied. Table 8 depicts this final structure location analysis. Similar to the LandScan to cadastral binary analysis, the categorical KIA values are extremely inconsistent, with values of 0.04 and 0.84. The problems associated with large Census blocks become more apparent with an extremely poor overall KIA value of 0.07 and an over prediction of 207,789 cells as occupied when only 16,975 actually are occupied.

2. Question 2: Locating the Wildland-Urban Interface

Each dataset (cadastral, LandScan, and SILVIS) underwent buffering, on a cell by cell basis (0.168 miles/270 meters at-a-time) creating buffers up to 1.5 miles thick (9-cell buffer); eighteen binary error matrices were created to summarize the spatial coincidence between the SILVIS/cadastral and the LandScan/cadastral datasets[4]. Significant error matrix results shall be discussed at the ½-mile and the 1½-mile distances; federally demarcated extents found in the HFRA of 2003.

[4] See **Appendix: WUI Location Error Matrices** for result tables; see **Appendix: WUI Location Maps** for result images.

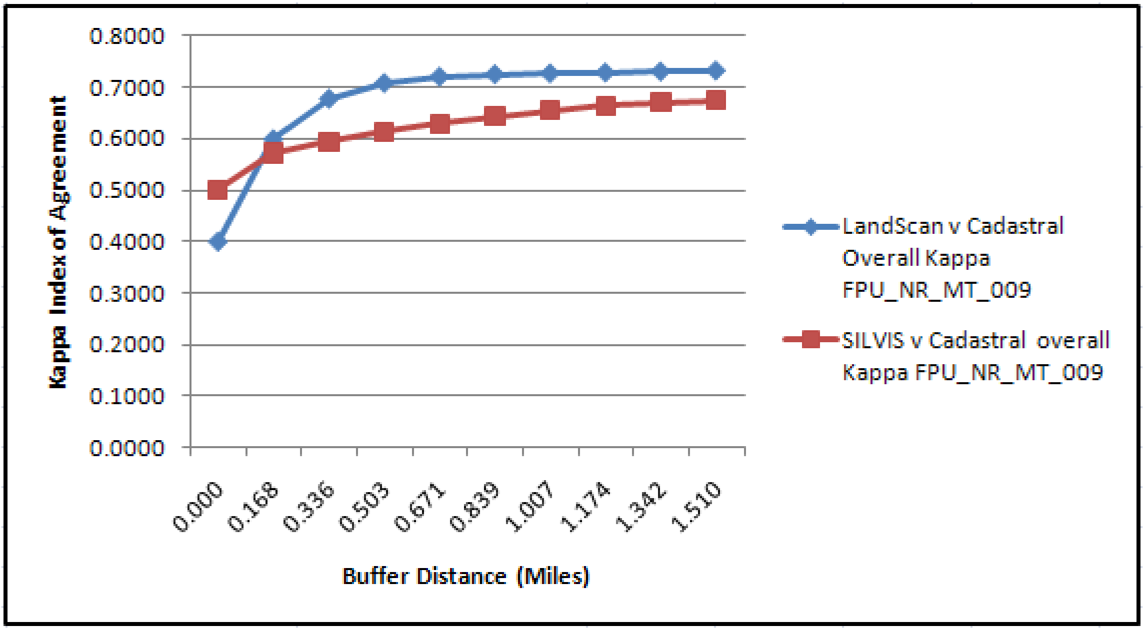


Figure 9. Comparison of overall Kappas.

Figure 9 depicts the overall KIA values of both the LandScan/cadastral and the SILVIS/cadastral error matrices from no buffer to a buffered extent of 1½-miles. Although the SILVIS dataset has a higher overall Kappa without any buffers (greater *true* structural location estimation), the LandScan dataset has greater KIA values at each buffered extent, indicating that it potentially predicts the *approximate* locations of structures (or WUI) more accurately than the SILVIS dataset. The greatest difference in overall KIA values occurs at the ½-mile mark, with the LandScan dataset having a good to very good overall Kappa of 0.71, and the SILVIS dataset retaining a moderate to good overall KIA of 0.61. As the buffer size increases, the LandScan dataset's overall KIA value increases slightly from 0.71 at ½-mile to 0.73 at 1½-miles. Although the SILVIS dataset's overall KIA values improve incrementally from 0.61 at ½-mile to 0.67 at 1½-miles, those values remain below the values registered by the LandScan dataset.

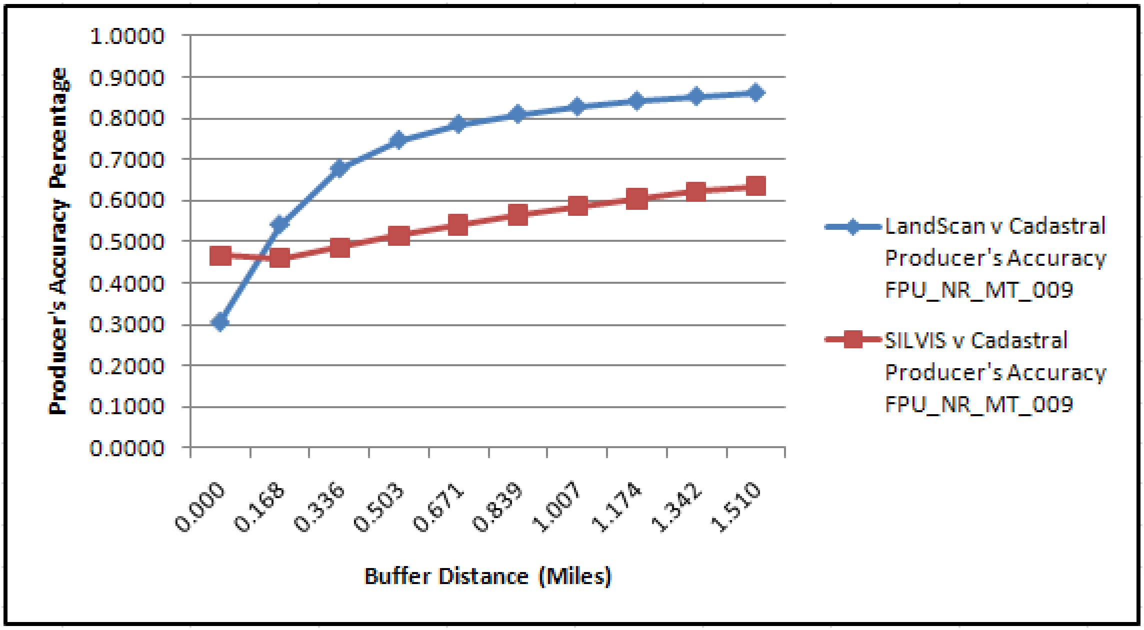


Figure 10. Comparison of Producer's categorical WUI Accuracies.

Figure 10 depicts the categorical WUI producer's accuracy from no buffer to a buffer of 1½-miles. Similar to the overall Kappa graph, the SILVIS dataset outperforms the LandScan dataset when no buffer is applied, and the LandScan retains a greater producer's accuracy value than the SILVIS dataset at every buffered extent with a greater than 20 percentage point difference at both the ½-mile and 1½-mile buffered extents; indicating that the LandScan dataset identifies cells in proximity to building clusters better than the SILVIS dataset.

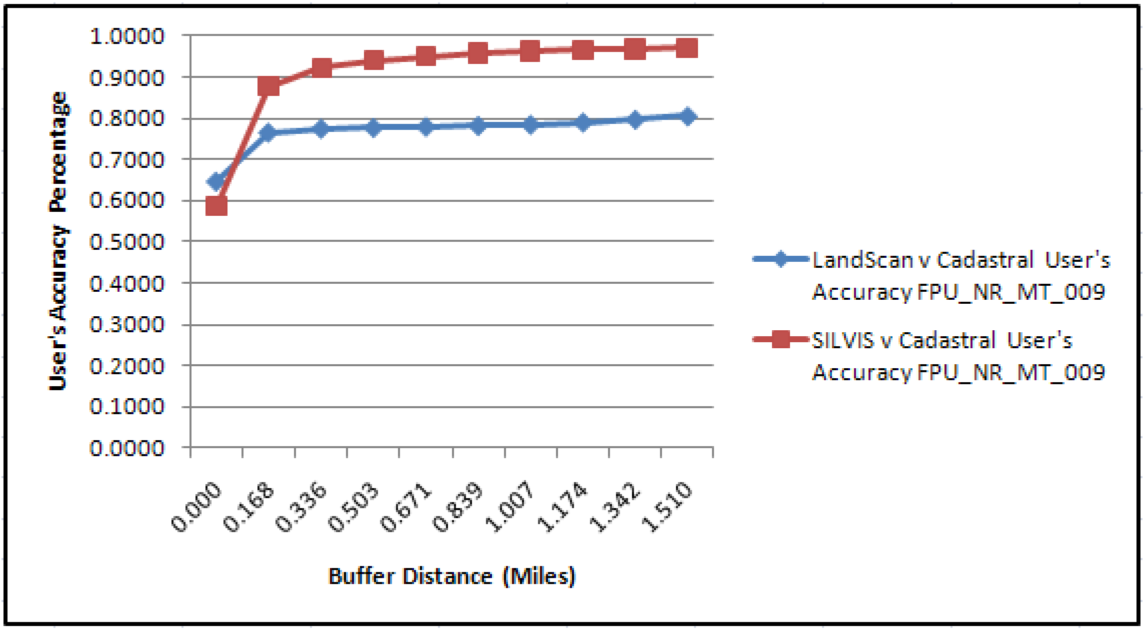


Figure 11. Comparison of User's categorical WUI Accuracies.

Conversely, the categorical WUI user's accuracy of the LandScan dataset renders a greater value than the SILVIS dataset without buffers, while the SILVIS data maintains a greater user's accuracy (typically 17 percentage points better) at each buffered extent than the LandScan data, as depicted in Figure 11. Although the LandScan data has a lower WUI user's accuracy value at each buffered extent, it retains a 78% success rate at the ½-mile buffer with a very good KIA of 0.73 and an 80% success rate at the 1½-mile extent with a KIA of 0.69, also indicating good to very good spatial coincidence.

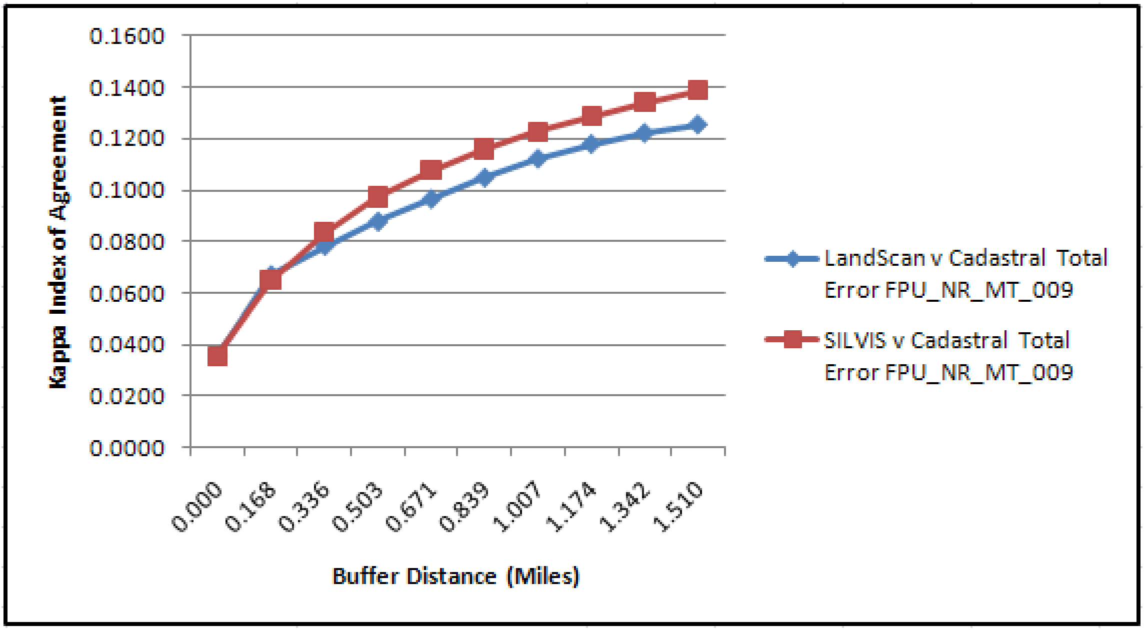


Figure 12. Comparison of total errors.

The total error created by each dataset is summarized in Figure 12. Notice the SILVIS dataset creates greater total error than the LandScan dataset at each measured extent (although the margin remains under 2 percentage points) except the 0.168-mile, 1-cell buffer. These results help to explain the greater overall KIA values found in the LandScan dataset.

Table 9. SILVIS - Cadastral 0.503-mile buffer WUI Error Matrix and KIA.

SILVIS: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	331,671	37,489	369,160	10%	90%	0.46
	WUI	2,556	39,614	42,170	6%	94%	0.93
	Total	334,227	77,103	411,330			
	Error of Ommision	1%	49%		10%		
	Producer's Accuracy	99%	51%			90%	
	Categorical Kappa	0.93	0.46			overall Kappa:	0.61

Table 10 LandScan - Cadastral 0.503-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	317,734	19,541	337,275	6%	94%	0.69
	WUI	16,493	57,562	74,055	22%	78%	0.73
	Total	334,227	77,103	411,330			
	Error of Ommision	5%	25%		9%		
	Producer's Accuracy	95%	75%			91%	
	Categorical Kappa	0.73	0.69			overall Kappa:	0.71

Delving further into the error matrix tables generated at the ½-mile interval, as depicted in Table 9 and Table 10, the SILVIS dataset boasts high user's accuracies (≥90%). Yet, the categorical KIA values are less consistent, with the Non-WUI Kappa at a moderate 0.46 and the WUI KIA at an excellent 0.93, indicating that when the SILVIS dataset predicts that a specific location is within the WUI, there is a very strong likelihood that location is indeed located within the WUI. However, the producer's accuracy of the WUI is only 51% with a moderate categorical KIA of 0.46, signifying that the SILVIS dataset does not identify all potential WUI locations. Notice the cadastral dataset designates 77,103 cells within the ½-mile buffer WUI, while the SILVIS dataset assigns only 42,170 pixels (55% of cadastral WUI). Whereas, the LandScan categorical KIA values (0.73 and 0.69) vary little from their good to very good overall KIA of 0.71. This indicates that although the WUI user's accuracy is lower with the LandScan data, LandScan has a greater WUI producer's accuracy and identifies approximately the same number of pixels (74,055 or 96%) as WUI as does the cadastral data. The LandScan data identifies a WUI area similar in size to the area demarcated by the cadastral data, and those regions are more spatially coincident (KIA of 0.71) than the corresponding SILVIS to cadastral data (0.61).

Table 11. SILVIS - Cadastral 1.510-mile buffer WUI Error Matrix and KIA.

SILVIS: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	260,025	54,181	314,206	17%	83%	0.52
	WUI	2,888	94,236	97,124	3%	97%	0.95
	Total	262,913	148,417	411,330			
	Error of Ommision	1%	37%		14%		
	Producer's Accuracy	99%	63%			86%	
	Categorical Kappa	0.95	0.52			overall Kappa:	0.67

Table 12. LandScan - Cadastral 1.510-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	231,947	20,596	252,543	8%	92%	0.77
	WUI	30,966	127,821	158,787	20%	80%	0.69
	Total	262,913	148,417	411,330			
	Error of Ommision	12%	14%		13%		
	Producer's Accuracy	88%	86%			87%	
	Categorical Kappa	0.69	0.77			overall Kappa:	0.73

Evaluating the 1½-mile buffer error matrices forming Table 11 and Table 12 reveals similar findings to the ½-mile buffer analysis. Once again, the SILVIS data under-predicts the extent of the WUI (97,124 / 148,417 = 65%); at the 1½-mile buffer WUI, the LandScan data over-predicts WUI size by 7% (158,787 / 148,417 = 107%). Other values also show slight increases maintaining their proportionate relationships to each other with a few exceptions. The total error increases for both datasets due to lower Non-WUI categorical accuracy values; a lower Non-WUI user's accuracy in the SILVIS data and a lower Non-WUI producer's accuracy in the LandScan data. These errors become evident when exploring the WUI Location images.

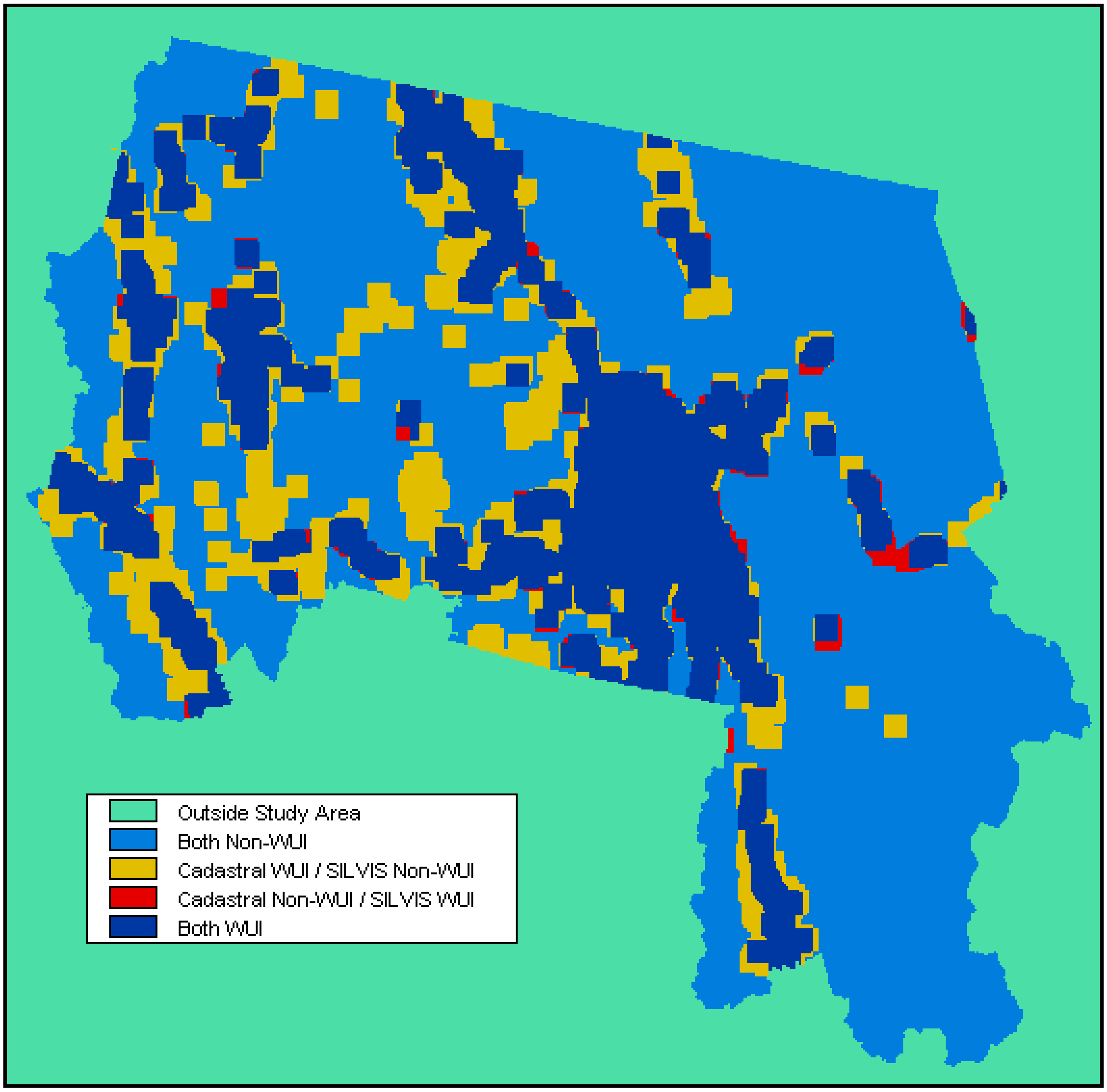


Figure 13. SILVIS - Cadastral 1.510-mile buffer WUI Map.

The SILVIS/cadastral overlay map with a buffer of 1.510-miles is depicted in Figure 13. Errors of commission are represented by the areas colored red and depict regions identified as WUI that do not have any structures nearby; whereas, errors of omission are represented by the areas colored yellow and show neighborhoods that should have been identified as WUI, but were not. The high WUI user's accuracy of the SILVIS dataset is confirmed on the image with very little red colored regions indicating that when the SILVIS dataset designates a place as belonging within the WUI, 97% of the time, it is. However, the low WUI producer's accuracy is evident with large expanses of yellow colored cells, indicating that the SILVIS dataset fails to designate all WUI locales as belonging to the WUI. Of the 411,330 cells located within the study area, 57,069 were identified incorrectly by the SILVIS dataset; 95% (54,181) of those cells were incorrectly designated as Non-WUI.

The LandScan/cadastral overlay image with a 1.510-mile buffer has a more even distribution between the red cells (errors of commission) and yellow cells (errors of omission) as illustrated in Figure 14. Approximately 40% of the

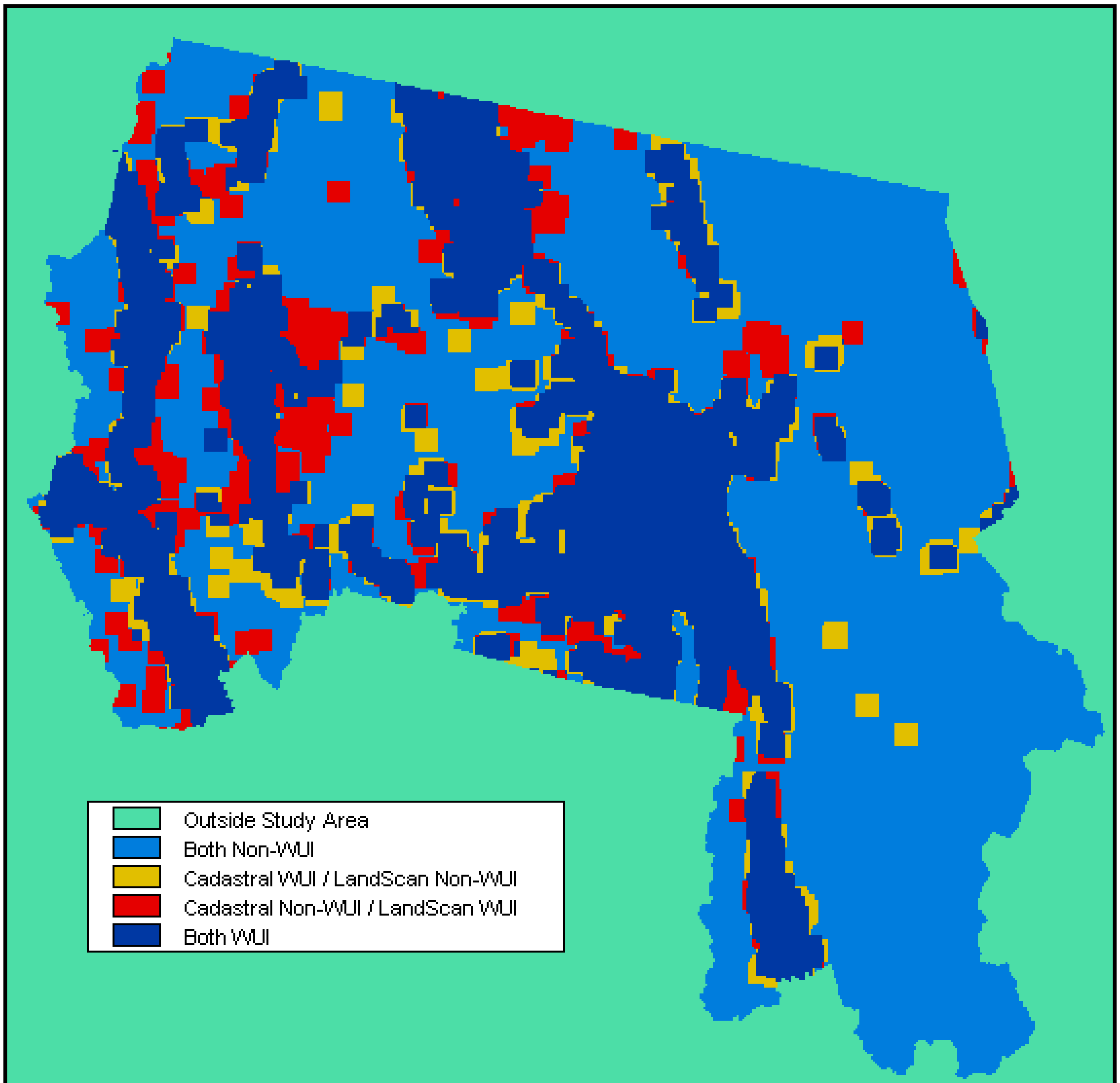


Figure 14. LandScan - Cadastral 1.510-mile buffer WUI Map.

incorrectly identified cells (20,596 cells) are errors of omission, an over-designation of the WUI. Not only does the LandScan dataset produce 33,585 less errors of omission, it appears to create less ‘islands’ of omission errors in that it is less likely to completely omit designating an area as belonging to the WUI. Note, both the SILVIS and the LandScan datasets have difficulty identifying isolated locations that the cadastral data indicates contain private and/or commercial structures; most ‘islands’ of omission errors occur in these remote corners.

V. CONCLUSION

The purpose of this research was to evaluate the LandScan USA population distribution database for the conterminous US as a nationally consistent proxy of structure location, and to ascertain whether its use as a basis to determine the WUI aids in wildland fire management and planning. The first question asked whether the LandScan population distribution data predicted the locations of structures derived from county cadastral data better than the SILVIS, Census block-level, data. When classifying the data employing the Intermix and Interface schema found within the Federal Register (USDA and DOI, 2001b), the SILVIS dataset outperforms the LandScan overall and categorical KIA values and has better user's and producer's accuracies. When analyzing the datasets with a binary occupied/unoccupied error matrix, the LandScan data had a greater user's accuracy (greater reliability) than the SILVIS data when identifying an area as being occupied. However, the extent of the occupied area of the LandScan was half the extent of the corresponding SILVIS and cadastral datasets indicating that the LandScan data do not predict the location of cadastral building clusters more accurately than do the SILVIS data. Furthermore, the spatial coincidence for the SILVIS data was only moderate, with the four class error matrix suggesting that the SILVIS data had the most difficulty predicting structures in low density areas.

The notion that larger Census blocks create larger spatial errors is also supported by the SILVIS four class error matrix which shows that the more dense an area (the smaller the Census block), the more accurate the classification. Also, the number of occupied cells in the final structural error matrix (Table 7) skyrocketed unrealistically when the 'Very Low Density' SILVIS classification was designated as occupied.

A possible explanation for the poor performance of the SILVIS and LandScan datasets lies in the relative ages of the datasets; both datasets are based on 2000 Census data, which is almost 10 years old at the time of this analysis. These values should improve with the 2010 Census for it will incorporate buildings constructed since 2000. The cadastral dataset, however, was attained from NRIS in January of 2008 (approximately 2 year-old data) and contains information about structures that may not have existed in the year 2000. In addition, the cadastral dataset does not predict individual structure location and places each building cluster at the geographic center point of its respective parcel (constrained within). Although it has been found that these building clusters retain a high level of locational accuracy (Calkin, et al., in review), errors are more likely to occur on larger parcels, in areas of relatively lower density.

Given the age of the Census data, it was believed that the additional data inputs used to create the LandScan dataset (which are updated annually) would have helped to alleviate the issue of dated data. Therefore, it is somewhat surprising that this research found the overall spatial coincidence of the SILVIS data to be greater than that of the LandScan data.

The second question posed in this research asks if the LandScan population distribution database can serve as a basis to create a finer-scale WUI map than the existing SILVIS WUI map produced using Census block-level data. As mentioned in the discussion, the SILVIS data have high user's accuracy and KIA values, but low producer's accuracy and KIA combining to create an overall accuracy and overall KIA lower than the corresponding LandScan values whose categorical values are much more consistent with its overall values. Also, the extent of the LandScan WUI more closely matches the extent of the cadastral WUI at both the ½-mile and 1½-mile buffer extents suggesting that while the LandScan data primarily lack locational accuracy (yet retains very good spatial coincidence with the cadastral data), the SILVIS data primarily under-predict the size of the WUI (while retaining excellent user's accuracy and user's categorical KIA values in areas it designated as WUI). The degree of SILVIS WUI under-prediction is at such a level that the LandScan data produce slightly less total error than the SILVIS product.

Although the locational accuracy of the cadastral building clusters decreases as parcel size increases, this effect is reduced when buffers are extended to the datasets. These buffers essentially create a buffered clusters product that approximately estimates structure location, which is precisely the role the creators of the building clusters dataset intended for it (RMRS, 2008a). Additionally, due to ongoing development in areas in proximity to federal lands, the WUI is a continuously growing and moving target requiring frequent data updates and necessitating further accuracy assessments that could use the methods employed in this study as a guide. With an expanding WUI, knowing the approximate amount of land found within the WUI (even if it contains locational inaccuracies) provides valuable information to wildland fire managers and planners.

When the Census data are updated by the 2010 survey, they are expected to improve the producer's accuracy of the SILVIS dataset; this should result in more consistent conditional KIA values. However, the updated 2010 Census data should also improve on LandScan's ability to accurately predict human presence. This researcher is curious how updated Census data may change these findings. Nonetheless, the LandScan data seems to show promise as a base layer to determine the WUI.

1. Further Research

The research performed for this analysis was conducted on one relatively rural Fire Planning Unit. The addition of further FPUs, especially more urban ones, would provide information that could be compared to the NWMT FPU. The Southern Sierra FPU, Central Oregon FPU, and Central Florida FPU prototype areas would not only provide information about areas more urban than northwestern Montana, but also provide information from vastly different regions of the United States with their own unique WUI characteristics. Cadastral data are available for most of the counties within these additional prototype areas; however, the data collection criteria are not standardized from county to county, nor vetted at the state level, as performed by Montana NRIS. Of these prototype FPUs, the Central Oregon FPU may provide further insight towards the accuracy and viability of LandScan data to estimate the location of the WUI in regions with a larger population because it experience less development owing to strong land use controls in that state; the age of the data should have less of an effect on the results permitting stronger conclusions on whether the LandScan data represents an improved method of WUI estimation over the SILVIS techniques.

Combining the buffered LandScan data with the fire probability data and fire intensity data of FPA would allow for the creation of a WUI map measuring risk across the landscape. The FPA fire probability data and intensity data from each FPU could be assembled to create a national fire risk map, using fire spread probability and estimated structure location data, to aid in fire management decision making throughout the nation.

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APPENDIX

Federal Register

WUI Criteria

Federal agencies generally focus on communities that are described under the Interface and Intermix categories. For purposes of applying these categories and the subsequent criteria for evaluating risk to communities, a structure is defined as either a residence or a business facility, including Federal, State, and local government facilities. Structures do not include small improvements such as fences and wildlife watering devices (Figure 15).

URBAN WILDLAND INTERFACE COMMUNITY DEFINITION			
Category	Structures per acre	Population Density: people per square mile	Description
Interface	"usually" ≥ 3 (with shared municipal services)	≥ 250 (> 7 per 270m²)	1. Where structures directly abut wildland fuels. 2. There is a clear line of demarcation between structures and wildland fuels; wildland fuels do not generally continue into the developed area. 3. Fire protection is generally provided by a local government fire department with the responsibility to protect the structure from both an interior fire and an advancing wildland fire.
Intermix	≥ 1 / 40 acres (from 1 per 40 acres to "very close together"	28 – 250 (1 – 7 per 270m²)	1. Where structures are scattered throughout a wildland area. 2. No clear line of demarcation; wildland fuels are continuous outside of and within the developed area. 3. Fire protection districts funded by taxing authorities normally provide life and property fire protection and may also have wildland fire protection responsibilities.
Occluded	The development density for an occluded community is usually similar to those found in the interface community, but the occluded area is usually less than 1,000 acres in size.		1. Where structures abut an island of wildland fuels, often within a city (park or open space). 2. There is a clear line of demarcation between structures and wildland fuels. 3. Fire protection is normally provided by local government fire departments.

Figure 15. Federal Register WUI Community Definition, adapted from USDA and USDOI, 2001b.

Preliminary Criteria for Evaluating Risk to Communities

Risk Factor 1: Fire Behavior Potential (Figure 16)

PRELIMINARY CRITERIA FOR EVALUATING RISK TO COMMUNITIES	
RISK FACTOR 1: FIRE BEHAVIOR POTENTIAL	
Fire Behavior Potential	Description
Situation 1	1. Continuous fuels are in close proximity to structures. 2. Composition of surrounding fuels is conducive to crown fires or high intensity surface fires. 3. Steep slopes, predominantly south aspects, dense fuels, heavy duff, prevailing wind exposure, and/or ladder fuels that reduce fire fighting effectiveness. 4. History of large fires and/or high occurrence.
Situation 2	1. Moderate slopes, broken moderate fuels, and some ladder fuels. 2. Composition of surrounding fuels is conducive to torching and spotting. 3. Conditions may lead to moderate fire fighting effectiveness. 4. History of some large fires and/or moderate fire occurrence.
Situation 3	1. Grass and/or sparse fuels surround structures. 2. Infrequent wind exposure, flat terrain with little slop and/or predominantly a north aspect. 3. Fire fighting generally is highly effective. 4. No large fire history and/or low fire occurrence.

Figure 16. Federal Register Risk Factor 1: Fire Behavior Potential, adapted from USDA and USDOI, 2001b.

Risk Factor 2: Fire Behavior Potential (Figure 17)

PRELIMINARY CRITERIA FOR EVALUATING RISK TO COMMUNITIES	
RISK FACTOR 2: VALUES AT RISK	
Values at Risk	Description
Situation 1	1. Most closely represents an urban interface setting: high density of homes, businesses, and other facilities that continue across the interface; there is a lack of defensible space where personnel can safely work to provide protection. 2. Community watershed for municipal water is at high risk of being burned compared to other watersheds within that geographic region. 3. High potential for economic loss to the community and likely loss of housing units and/or businesses. 4. Unique cultural, historical, or natural heritage values at risk.
Situation 2	1. Most closely represents an intermix or occluded setting: scattered areas of high-density homes, summer homes, youth camps, or campgrounds that are less than a mile apart. 2. Includes the presence of lands at risk that are described under State designations such as impaired watersheds, or scenic byways. 3. Risk of erosion or flooding in the community if vegetation burns.

Figure 17. Federal Register Risk Factor 2: Values at Risk, adapted from USDA and USDOI, 2001b .

Risk Factor 3: Infrastructure (Figure 18)

PRELIMINARY CRITERIA FOR EVALUATING RISK TO COMMUNITIES	
RISK FACTOR 3: INFRASTRUCTURE	
Infrastructure	Description
Situation 1	1. Narrow dead end roads, steep grades, one way in and/or out routes. 2. No or minimal fire fighting capacity: no fire hydrants, no surface water, and no pressure water systems. 3. Area surrounded by a fire-conducive landscape. 4. No emergency operations group and no evacuation plan.
Situation 2	1. Limited access routes, moderate grades. 2. Limited fire fighting capability: limited water supply. 3. Area surrounded by scattered fire-conducive landscape.
Situation 3	1. Multiple entrances and exits. 2. Well equipped for fire trucks, wide loop roads, fire hydrants open water sources (pools, creeks, lakes). 3. Area surrounded by a fireproof landscape. 4. Active emergency operations group and an evacuation plan in place.

Figure 18. Federal Register Risk Factor 3: Infrastructure, adapted from USDA and USDOI, 2001b.

Structural Location Maps

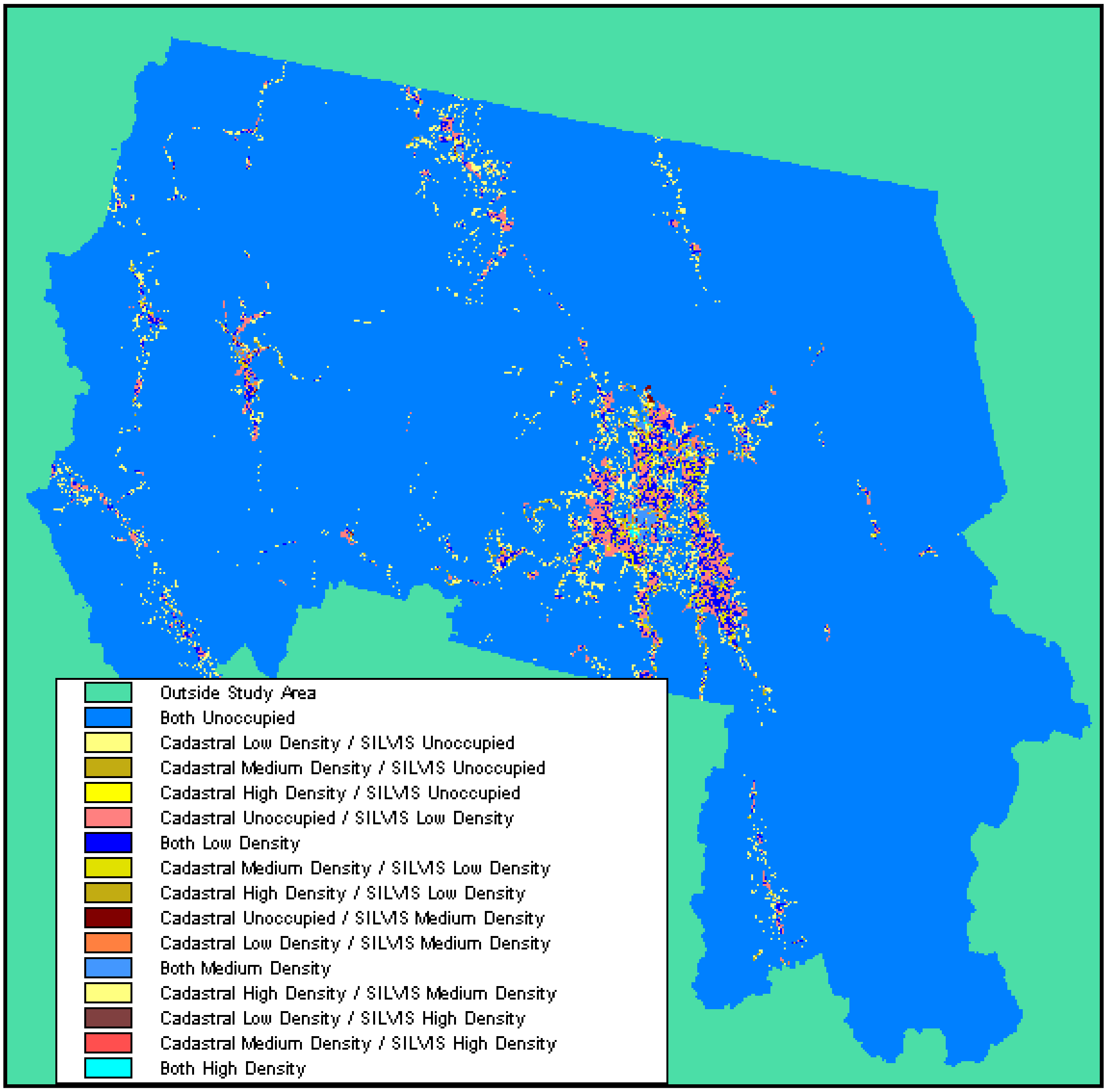

Figure 19. SILVIS - Cadastral 4 Classes Structural Map.

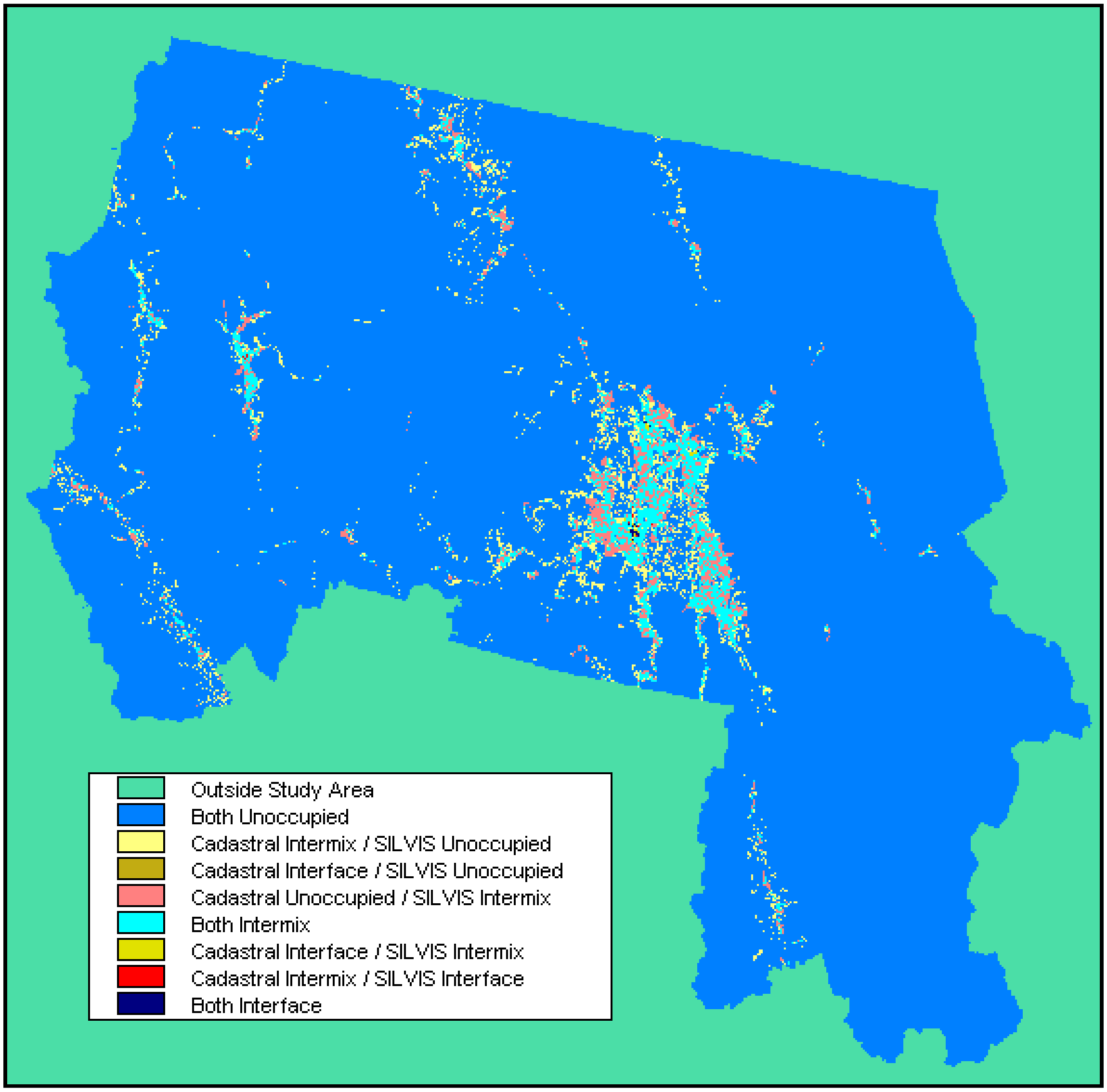

Figure 20. SILVIS - Cadastral 3 Classes Structural Map.

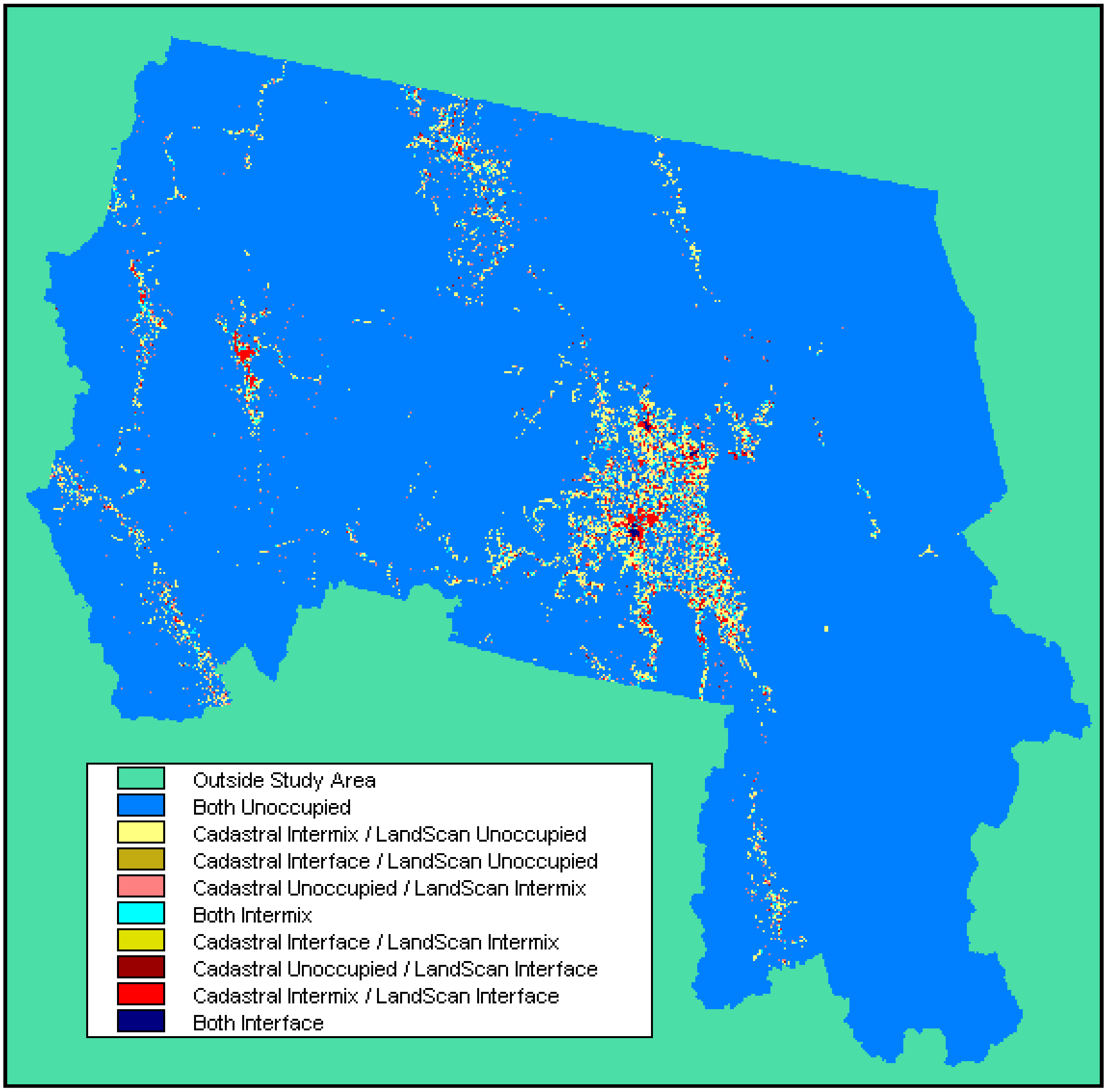

Figure 21. LandScan - Cadastral 3 Classes Structural Map.

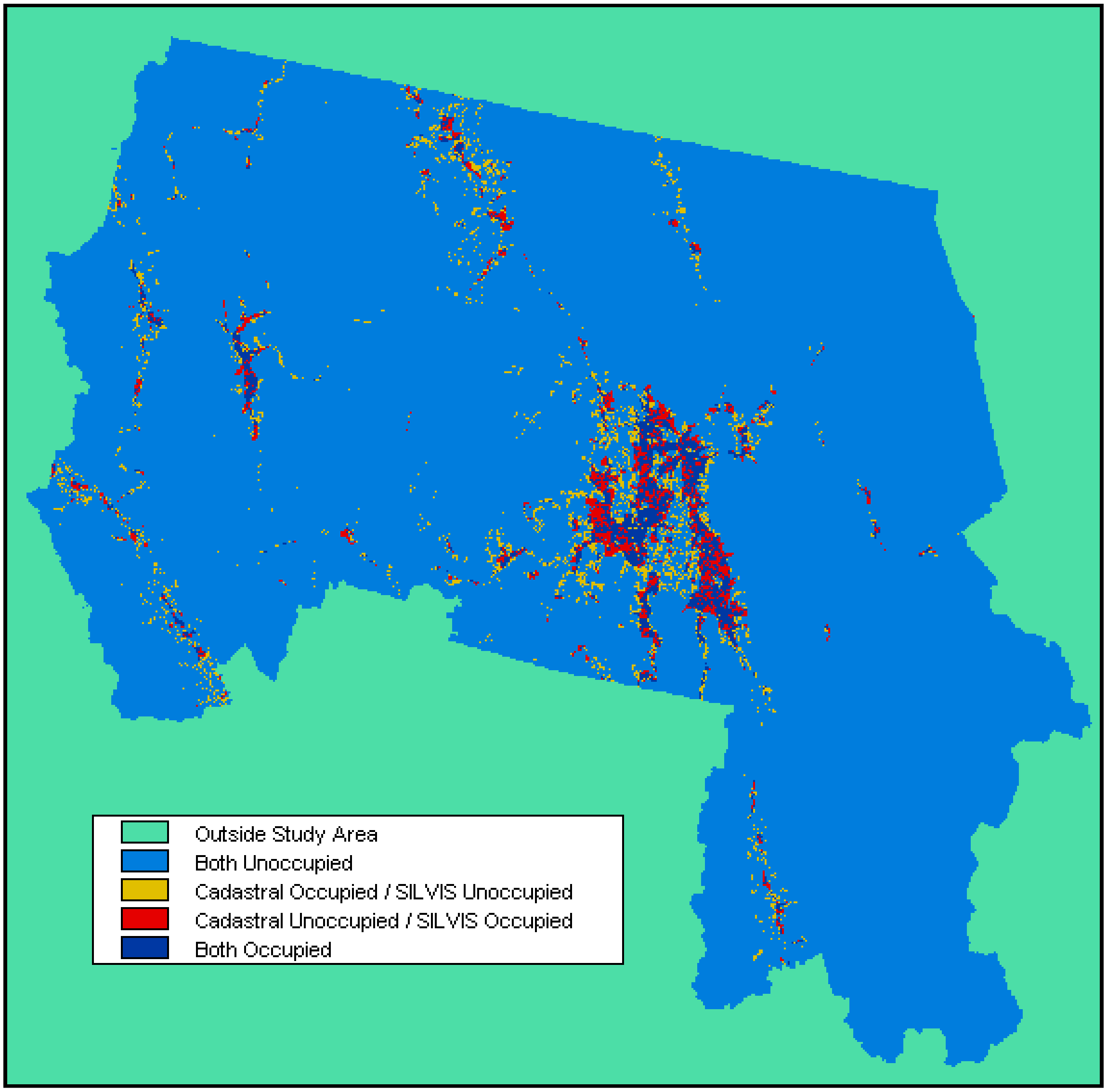

Figure 22. SILVIS - Cadastral 2 Classes Structural Map.

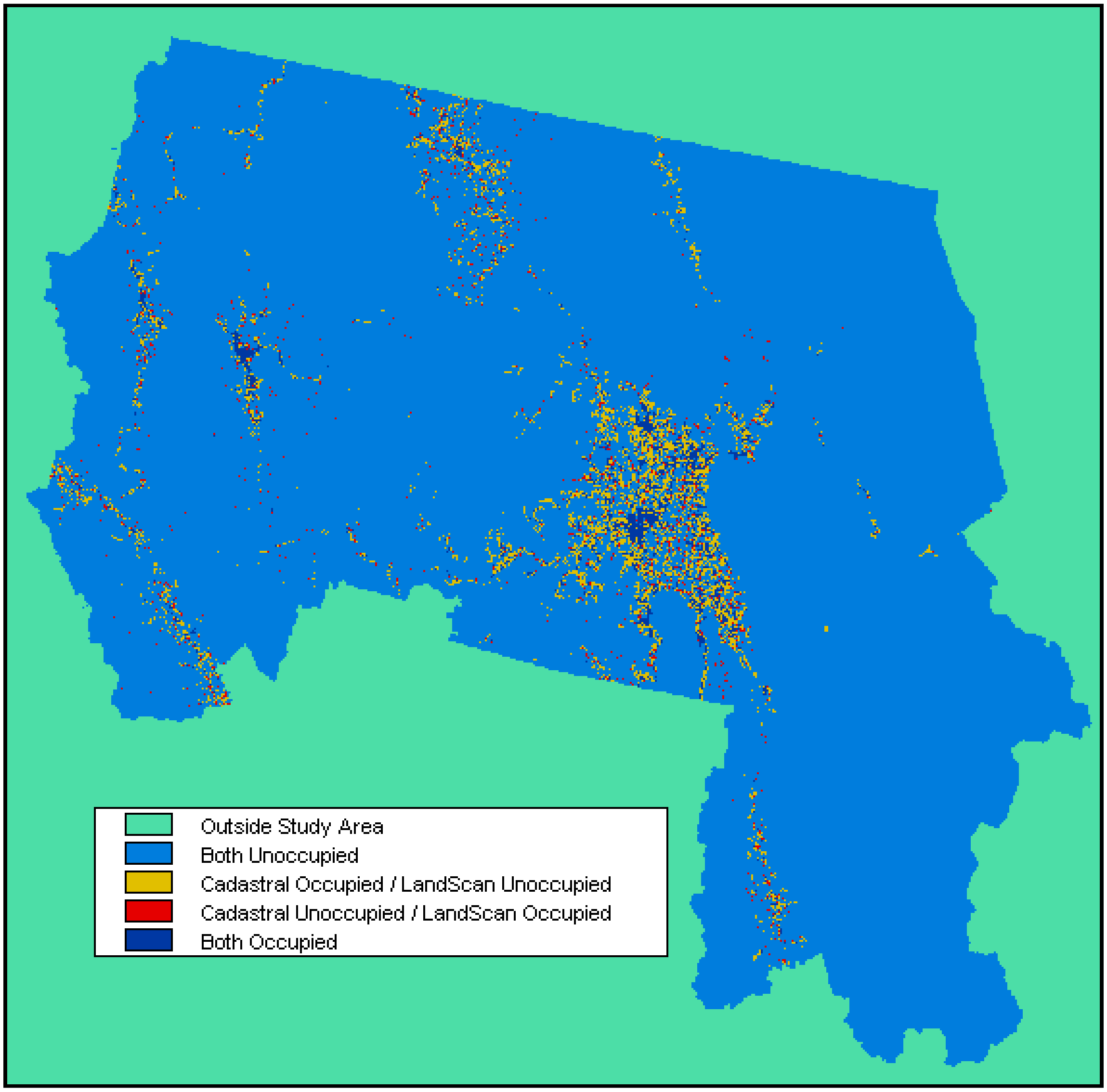

Figure 23. LandScan - Cadastral 2 Classes Structural Map.

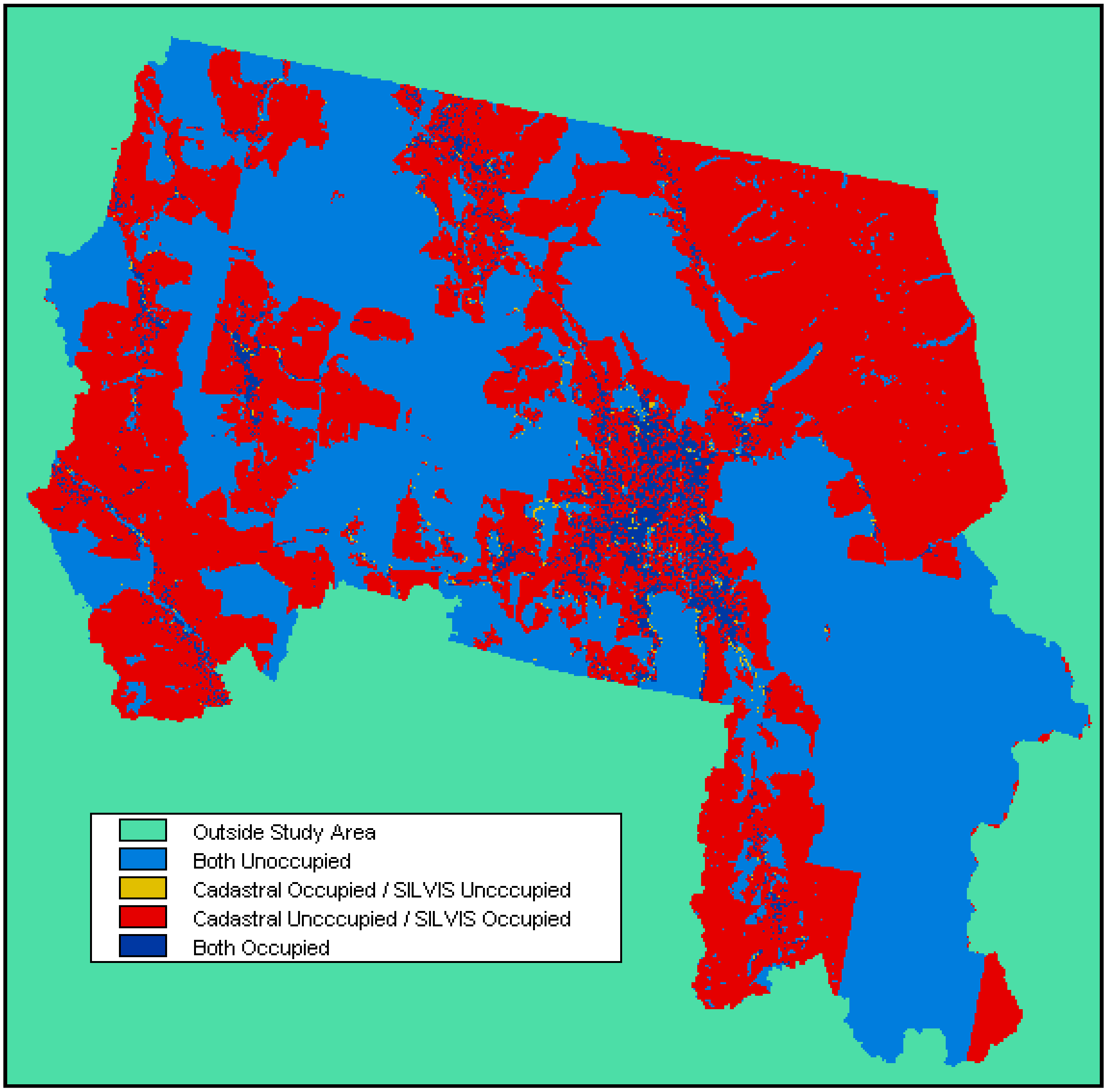

Figure 24. SILVIS - Cadastral 2 Classes Structural Map with Very Low as Occupied.

WUI Location Error Matrices

SILVIS – Cadastral WUI Location Error Matrices

Table 13. SILVIS - Cadastral 0.168-mile buffer WUI Error Matrix and KIA.

		Cadastral: Reference Image					
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Non-WUI	364,452	23,806	388,258	6%	94%	0.43
	WUI	2,842	20,230	23,072	12%	88%	0.86
	Total	367,294	44,036	411,330			
	Error of Ommision	1%	54%		6%		
	Producer's Accuracy	99%	46%			94%	
	Categorical Kappa	0.86	0.43			overall Kappa:	0.57

Table 14. SILVIS - Cadastral 0.336-mile buffer WUI Error Matrix and KIA.

		Cadastral: Reference Image					
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Non-WUI	346,843	31,833	378,676	8%	92%	0.44
	WUI	2,546	30,108	32,654	8%	92%	0.91
	Total	349,389	61,941	411,330			
	Error of Ommision	1%	51%		8%		
	Producer's Accuracy	99%	49%			92%	
	Categorical Kappa	0.91	0.44			overall Kappa:	0.59

Table 15 SILVIS - Cadastral 0.503-mile buffer WUI Error Matrix and KIA.

		Cadastral: Reference Image					
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Non-WUI	331,671	37,489	369,160	10%	90%	0.46
	WUI	2,556	39,614	42,170	6%	94%	0.93
	Total	334,227	77,103	411,330			
	Error of Ommision	1%	49%		10%		
	Producer's Accuracy	99%	51%			90%	
	Categorical Kappa	0.93	0.46			overall Kappa:	0.61

Table 16. SILVIS - Cadastral 0.671-mile buffer WUI Error Matrix and KIA.

		Cadastral: Reference Image					
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Non-WUI	317,979	41,753	359,732	12%	88%	0.47
	WUI	2,559	49,042	51,601	5%	95%	0.94
	Total	320,538	90,795	411,333			
	Error of Ommision	1%	46%		11%		
	Producer's Accuracy	99%	54%			89%	
	Categorical Kappa	0.94	0.47			overall Kappa:	0.63

Table 17. SILVIS - Cadastral 0.839-mile buffer WUI Error Matrix and KIA.

		Cadastral: Reference Image					
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Non-WUI	305,211	45,124	350,335	13%	87%	0.49
	WUI	2,578	58,417	60,995	4%	96%	0.94
	Total	307,789	103,541	411,330			
	Error of Ommision	1%	44%		12%		
	Producer's Accuracy	99%	56%			88%	
	Categorical Kappa	0.94	0.49			overall Kappa:	0.64

Table 18. SILVIS - Cadastral 1.007-mile buffer WUI Error Matrix and KIA.

		Cadastral: Reference Image					
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
SILVIS: Mapped	Non-WUI	293,233	47,831	341,064	14%	86%	0.50
	WUI	2,651	67,615	70,266	4%	96%	0.95
	Total	295,884	115,446	411,330			
	Error of Ommision	1%	41%		12%		
	Producer's Accuracy	99%	59%			88%	
	Categorical Kappa	0.95	0.50			overall Kappa:	0.65

Table 19. SILVIS - Cadastral 1.174-mile buffer WUI Error Matrix and KIA.

	Cadastral: Reference Image						
SILVIS: Mapped		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	281,785	50,192	331,977	15%	85%	0.51
	WUI	2,735	76,618	79,353	3%	97%	0.95
	Total	284,520	126,810	411,330			
	Error of Ommision	1%	40%		13%		
	Producer's Accuracy	99%	60%			87%	
	Categorical Kappa	0.95	0.51			overall Kappa:	0.66

Table 20. SILVIS - Cadastral 1.342-mile buffer WUI Error Matrix and KIA.

	Cadastral: Reference Image						
SILVIS: Mapped		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	270,711	52,280	322,991	16%	84%	0.52
	WUI	2,833	85,506	88,339	3%	97%	0.95
	Total	273,544	137,786	411,330			
	Error of Ommision	1%	38%		13%		
	Producer's Accuracy	99%	62%			87%	
	Categorical Kappa	0.95	0.52			overall Kappa:	0.67

Table 21. SILVIS - Cadastral 1.510-mile buffer WUI Error Matrix and KIA.

	Cadastral: Reference Image						
SILVIS: Mapped		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	260,025	54,181	314,206	17%	83%	0.52
	WUI	2,888	94,236	97,124	3%	97%	0.95
	Total	262,913	148,417	411,330			
	Error of Ommision	1%	37%		14%		
	Producer's Accuracy	99%	63%			86%	
	Categorical Kappa	0.95	0.52			overall Kappa:	0.67

LandScan – Cadastral WUI Location Error Matrices

Table 22 LandScan - Cadastral 0.168-mile buffer WUI Error Matrix and KIA.

	Cadastral: Reference Image					
LandScan: Mapped	Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
Non-WUI	360,006	20,202	380,208	5%	95%	0.50
WUI	7,288	23,834	31,122	23%	77%	0.74
Total	367,294	44,036	411,330			
Error of Ommision	2%	46%		7%		
Producer's Accuracy	98%	54%			93%	
Categorical Kappa	0.74	0.50			overall Kappa:	0.60

Table 23 LandScan - Cadastral 0.336-mile buffer WUI Error Matrix and KIA.

	Cadastral: Reference Image					
LandScan: Mapped	Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
Non-WUI	337,221	20,006	357,227	6%	94%	0.63
WUI	12,168	41,935	54,103	22%	78%	0.74
Total	349,389	61,941	411,330			
Error of Ommision	3%	32%		8%		
Producer's Accuracy	97%	68%			92%	
Categorical Kappa	0.74	0.63			overall Kappa:	0.68

Table 24 LandScan - Cadastral 0.503-mile buffer WUI Error Matrix and KIA.

	Cadastral: Reference Image					
LandScan: Mapped	Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
Non-WUI	317,734	19,541	337,275	6%	94%	0.69
WUI	16,493	57,562	74,055	22%	78%	0.73
Total	334,227	77,103	411,330			
Error of Ommision	5%	25%		9%		
Producer's Accuracy	95%	75%			91%	
Categorical Kappa	0.73	0.69			overall Kappa:	0.71

Table 25 LandScan - Cadastral 0.671-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	300,394	19,512	319,906	6%	94%	0.72
	WUI	20,141	71,283	91,424	22%	78%	0.72
	Total	320,535	90,795	411,330			
	Error of Ommision	6%	21%		10%		
	Producer's Accuracy	94%	79%			90%	
	Categorical Kappa	0.72	0.72			overall Kappa:	0.72

Table 26 LandScan - Cadastral 0.839-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	284,440	19,725	304,165	6%	94%	0.74
	WUI	23,349	83,816	107,165	22%	78%	0.71
	Total	307,789	103,541	411,330			
	Error of Ommision	8%	19%		10%		
	Producer's Accuracy	92%	81%			90%	
	Categorical Kappa	0.71	0.74			overall Kappa:	0.73

Table 27 LandScan - Cadastral 1.007-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	269,713	19,946	289,659	7%	93%	0.75
	WUI	26,171	95,500	121,671	22%	78%	0.70
	Total	295,884	115,446	411,330			
	Error of Ommision	9%	17%		11%		
	Producer's Accuracy	91%	83%			89%	
	Categorical Kappa	0.70	0.75			overall Kappa:	0.73

Table 28 LandScan - Cadastral 1.174-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	256,218	20,156	276,374	7%	93%	0.76
	WUI	28,302	106,654	134,956	21%	79%	0.70
	Total	284,520	126,810	411,330			
	Error of Ommision	10%	16%		12%		
	Producer's Accuracy	90%	84%			88%	
	Categorical Kappa	0.70	0.76			overall Kappa:	0.73

Table 29 LandScan - Cadastral 1.342-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	243,635	20,327	263,962	8%	92%	0.77
	WUI	29,909	117,459	147,368	20%	80%	0.69
	Total	273,544	137,786	411,330			
	Error of Ommision	11%	15%		12%		
	Producer's Accuracy	89%	85%			88%	
	Categorical Kappa	0.69	0.77			overall Kappa:	0.73

Table 30 LandScan - Cadastral 1.510-mile buffer WUI Error Matrix and KIA.

LandScan: Mapped	Cadastral: Reference Image						
		Non-WUI	WUI	total	Error of Commision	User's Accuracy	KIA
	Non-WUI	231,947	20,596	252,543	8%	92%	0.77
	WUI	30,966	127,821	158,787	20%	80%	0.69
	Total	262,913	148,417	411,330			
	Error of Ommision	12%	14%		13%		
	Producer's Accuracy	88%	86%			87%	
	Categorical Kappa	0.69	0.77			overall Kappa:	0.73

WUI Location Maps

SILVIS – Cadastral WUI Location Maps

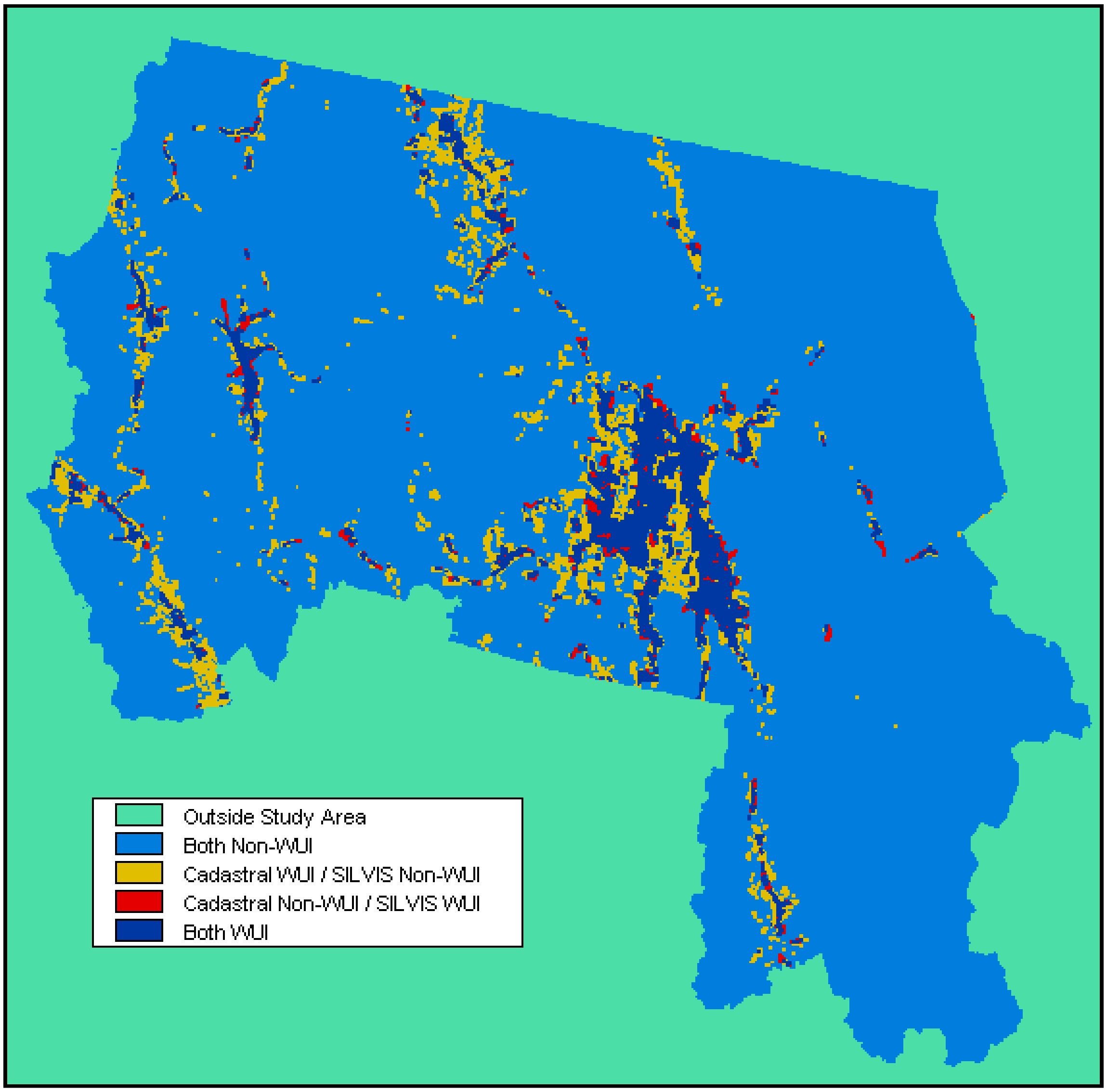

Figure 25. SILVIS - Cadastral 0.168-mile buffer WUI Map.

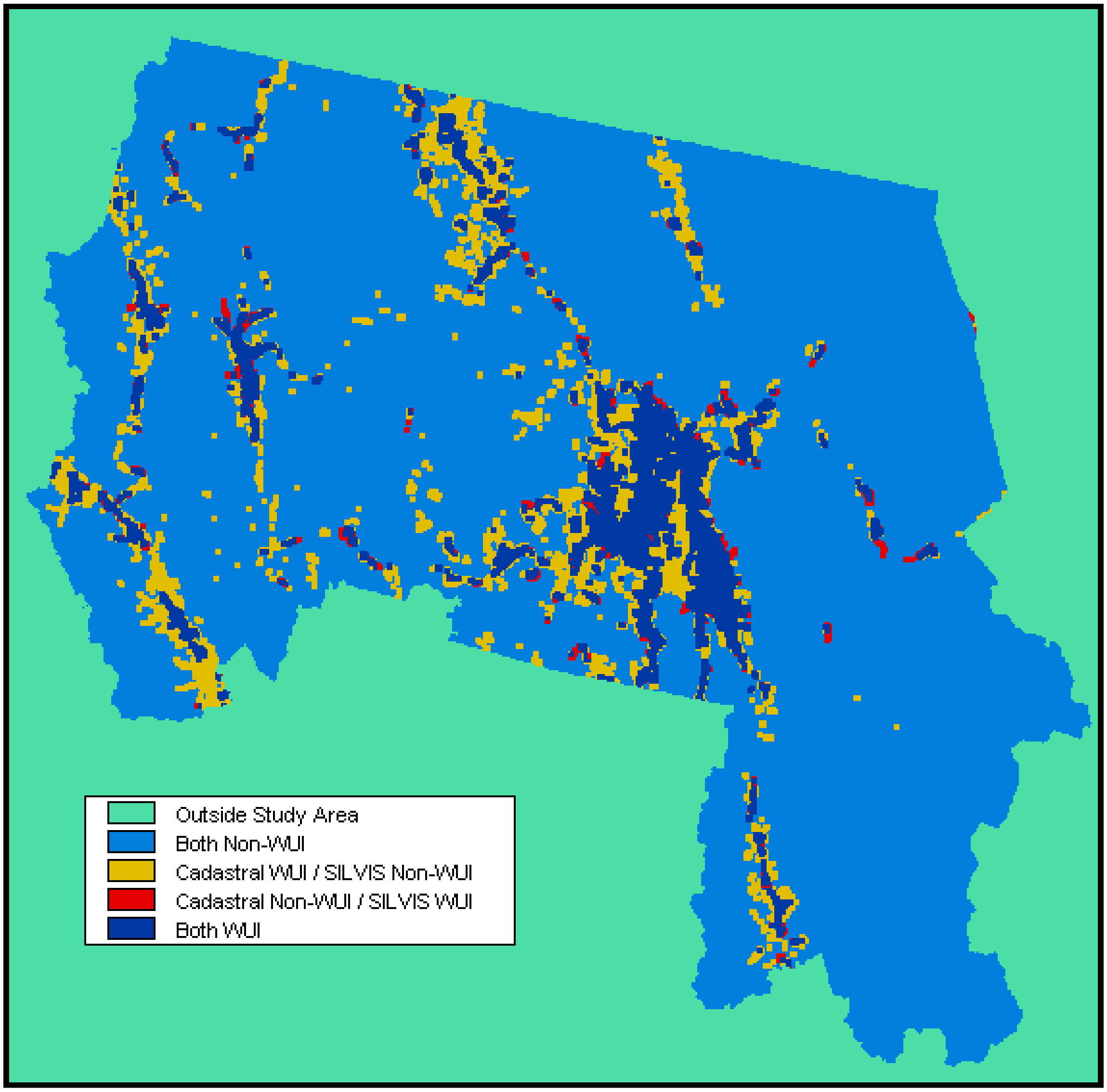

Figure 26. SILVIS - Cadastral 0.336-mile buffer WUI Map.

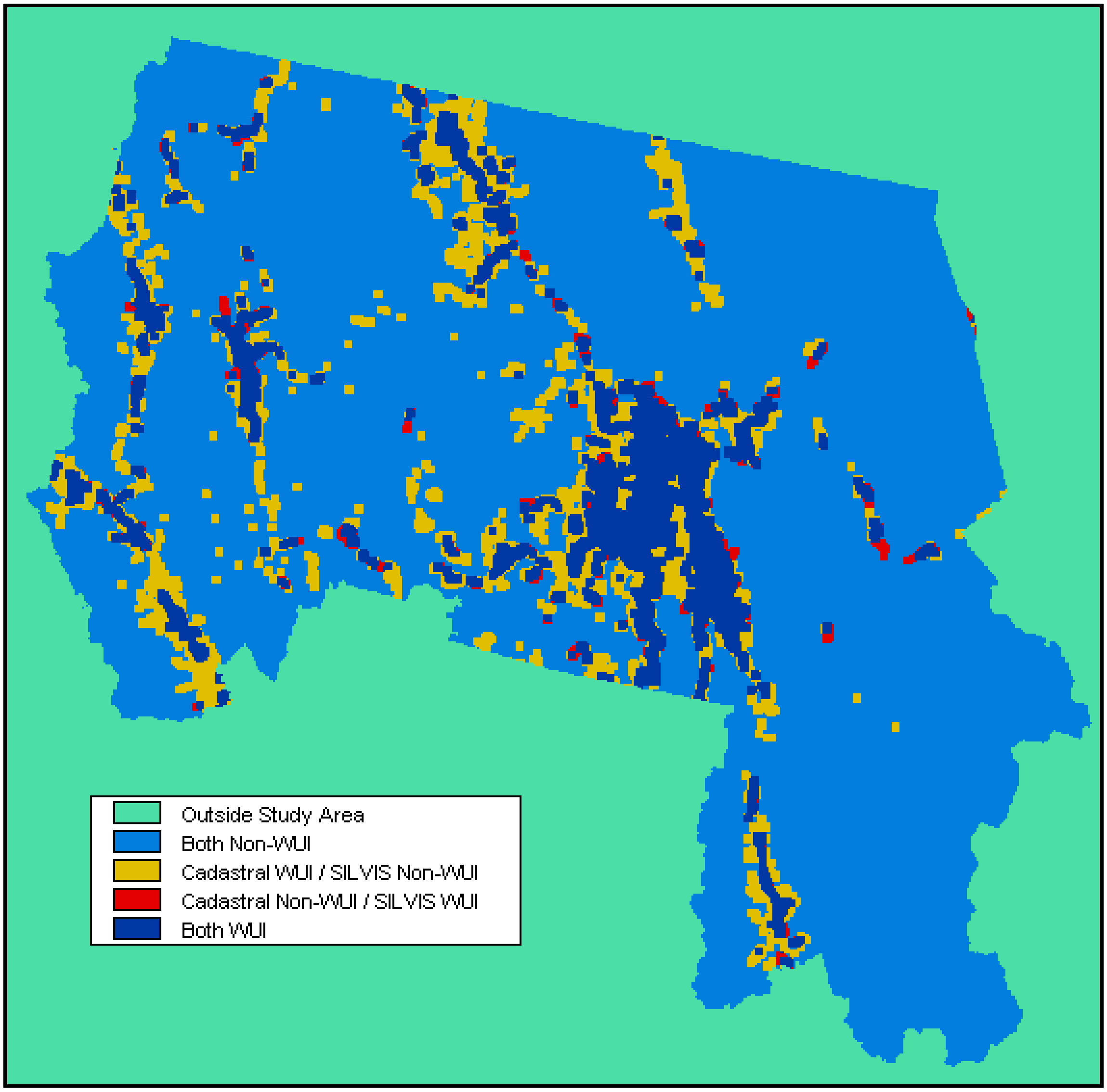

Figure 27. SILVIS - Cadastral 0.503-mile buffer WUI Map.

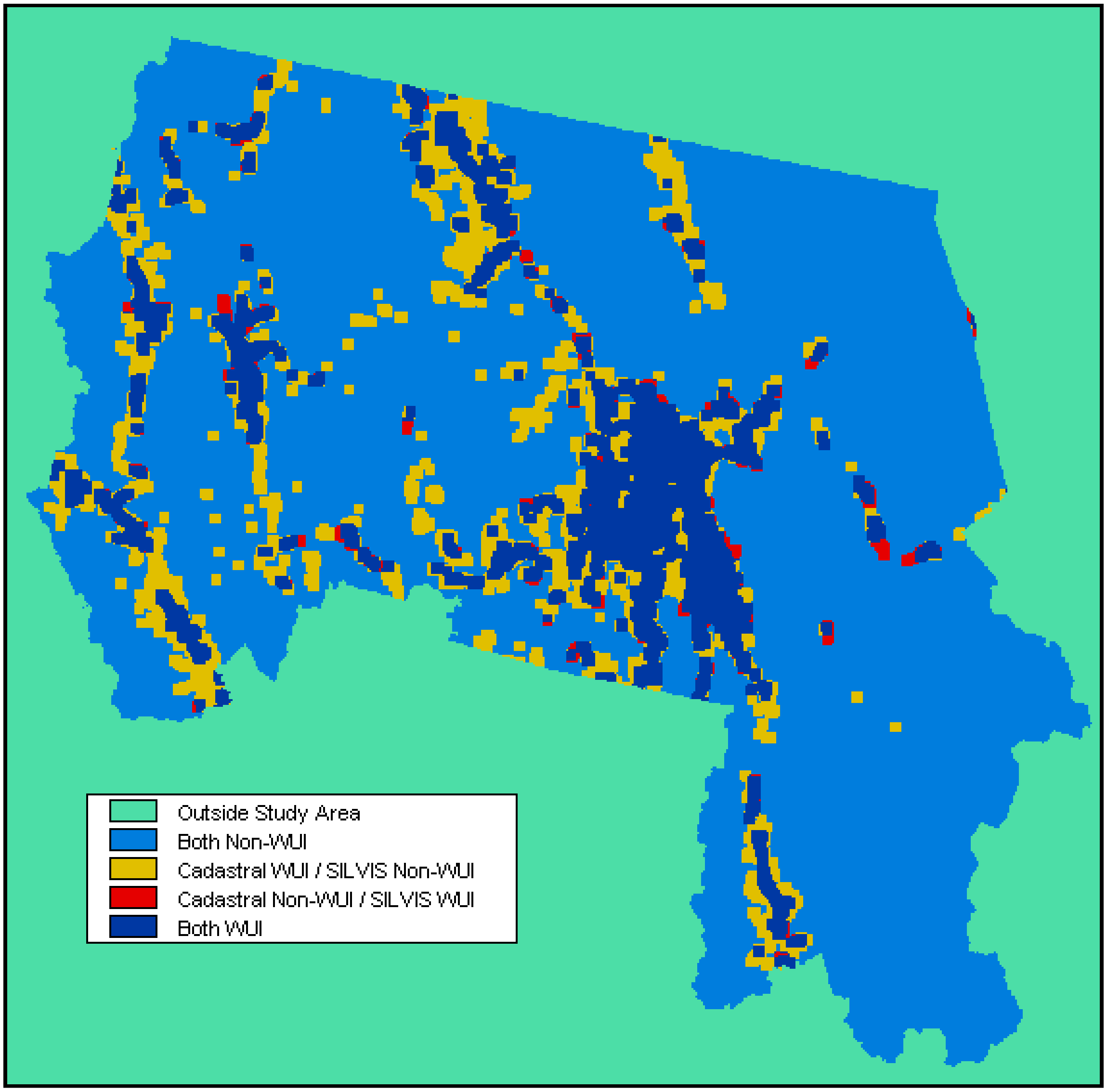

Figure 28. SILVIS - Cadastral 0.671-mile buffer WUI Map.

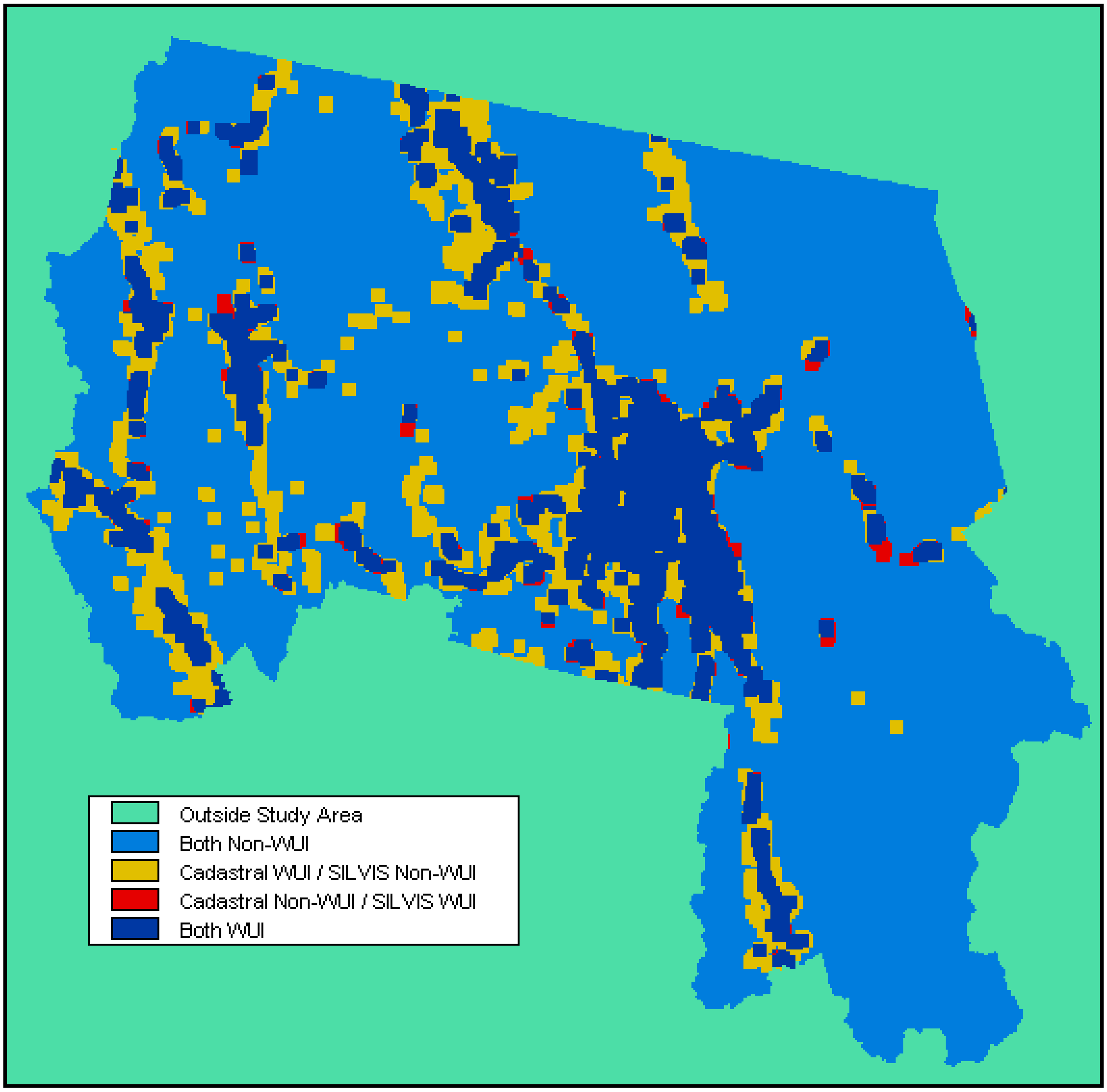

Figure 29. SILVIS - Cadastral 0.839-mile buffer WUI Map.

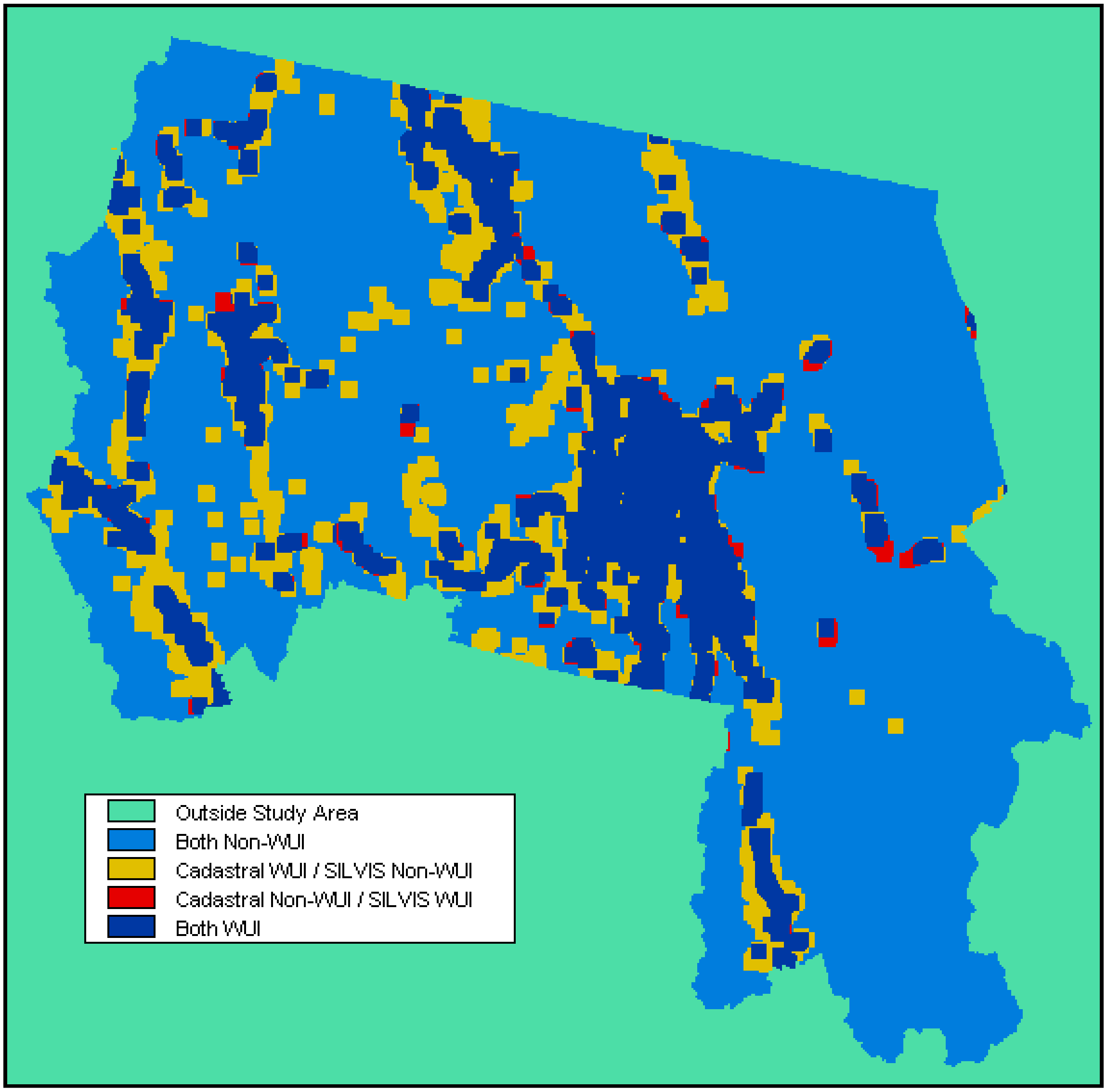

Figure 30. SILVIS - Cadastral 1.007-mile buffer WUI Map.

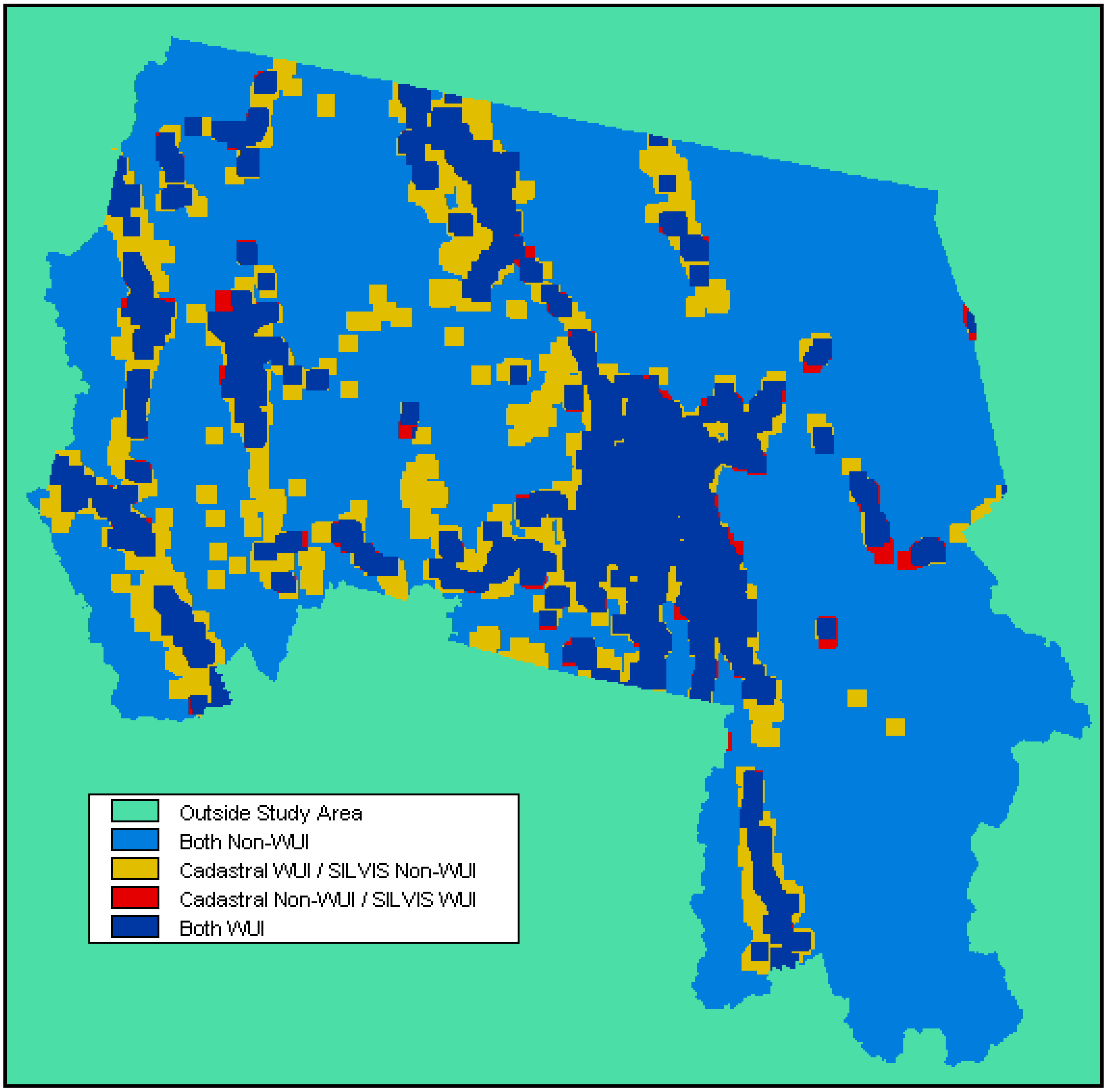

Figure 31. SILVIS - Cadastral 1.174-mile buffer WUI Map.

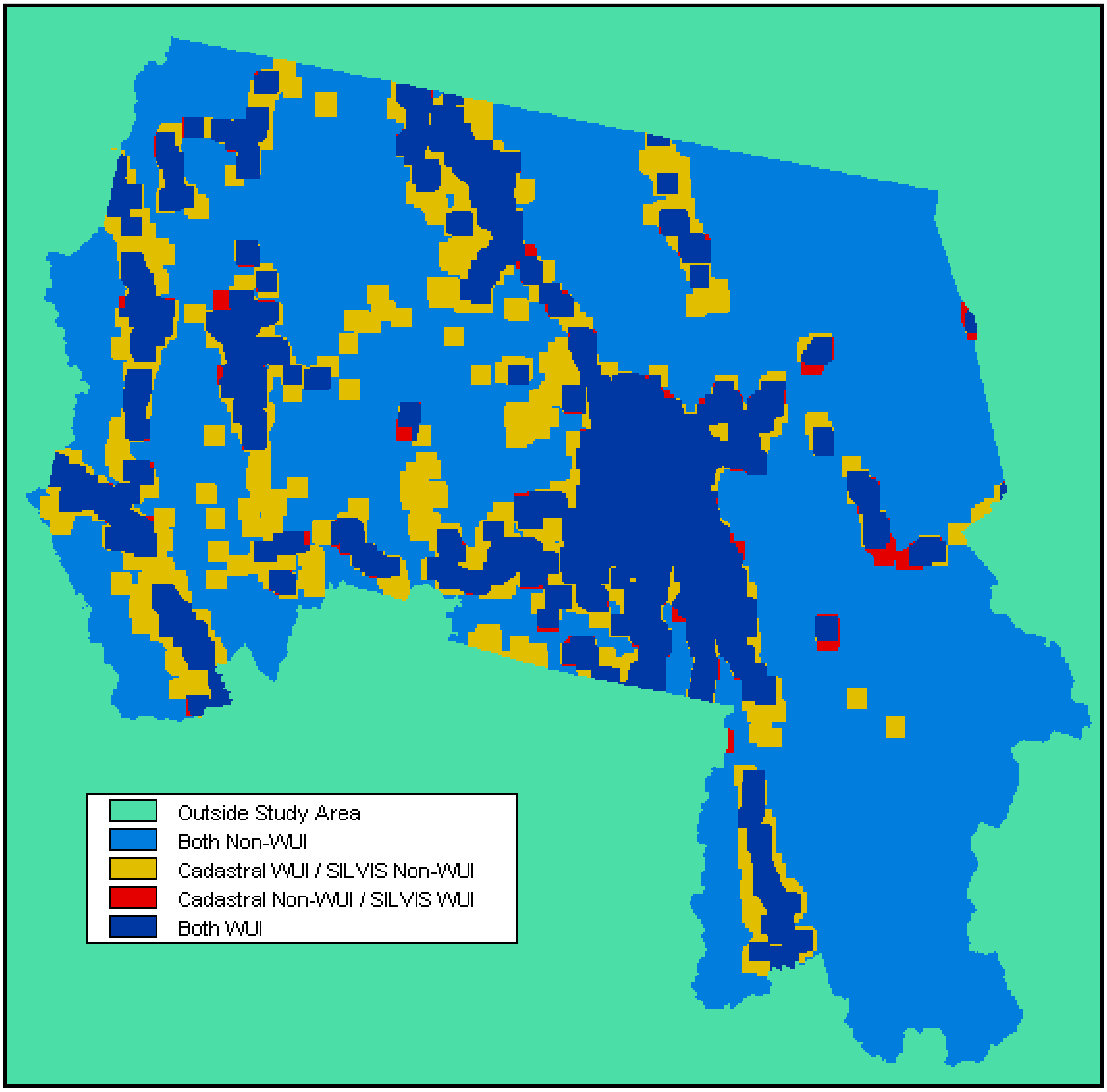

Figure 32. SILVIS - Cadastral 1.342-mile buffer WUI Map.

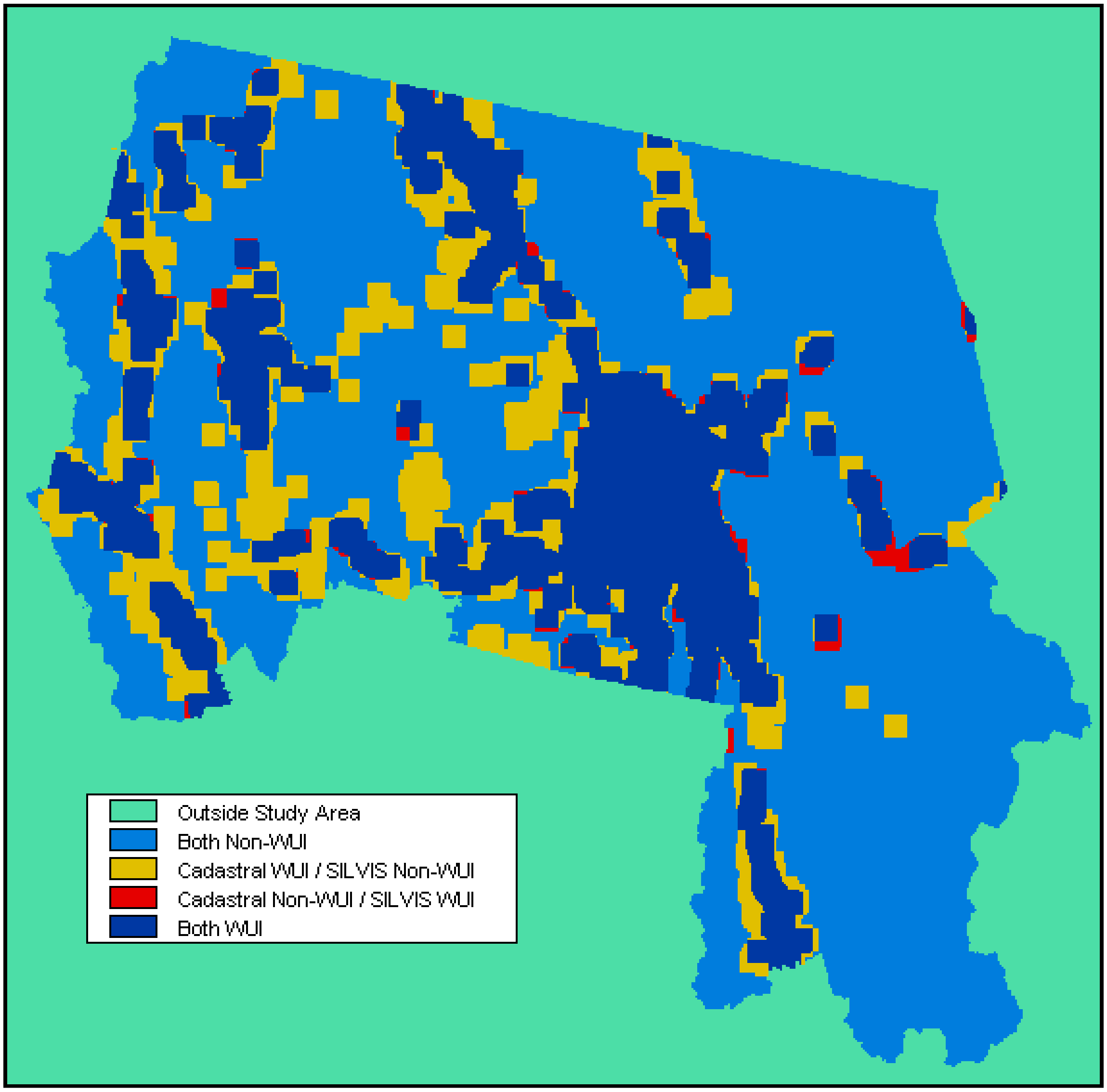

Figure 33. SILVIS - Cadastral 1.510-mile buffer WUI Map.

LandScan – Cadastral WUI Location Maps

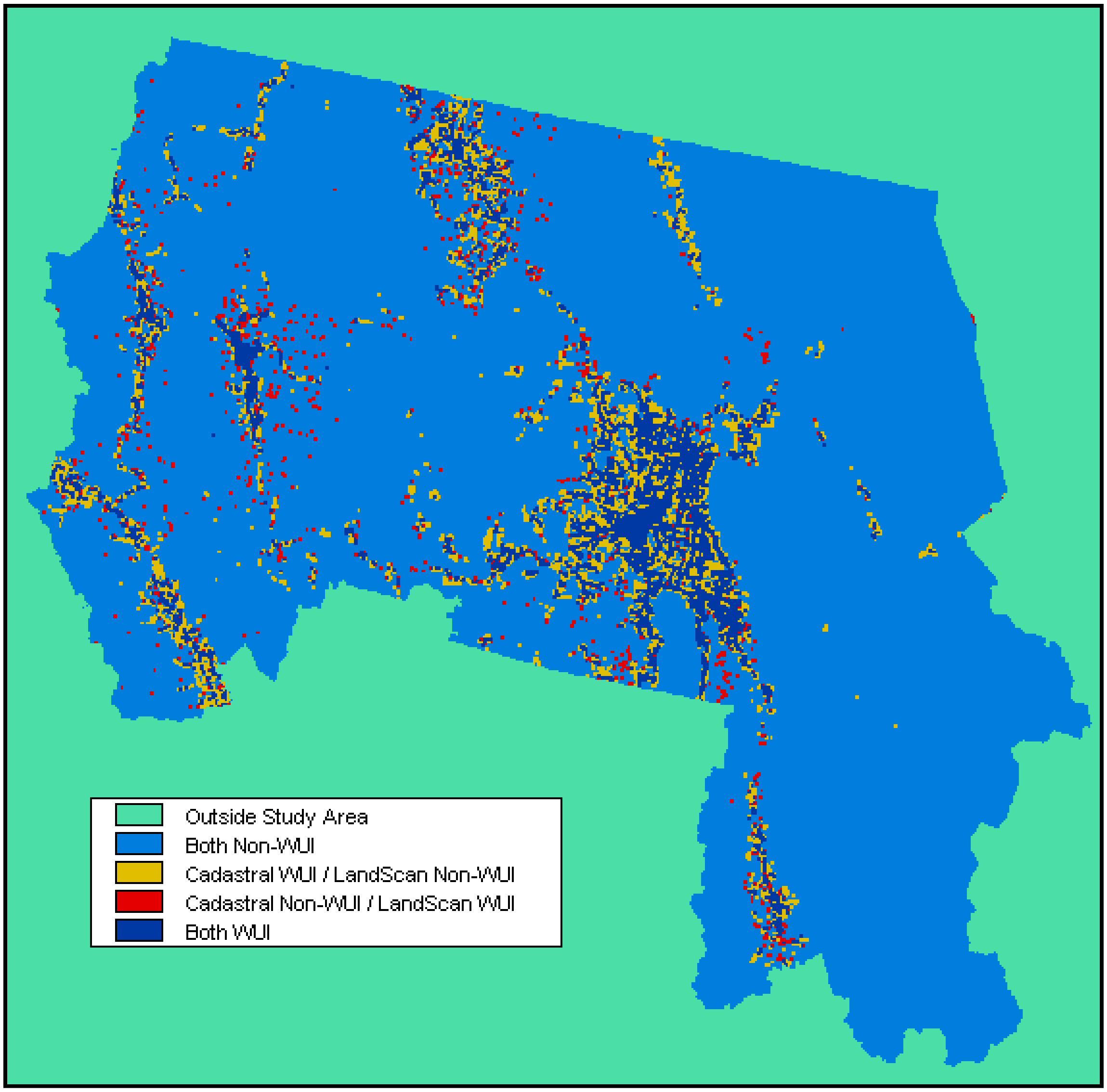

Figure 34. LandScan - Cadastral 0.168-mile buffer WUI Map.

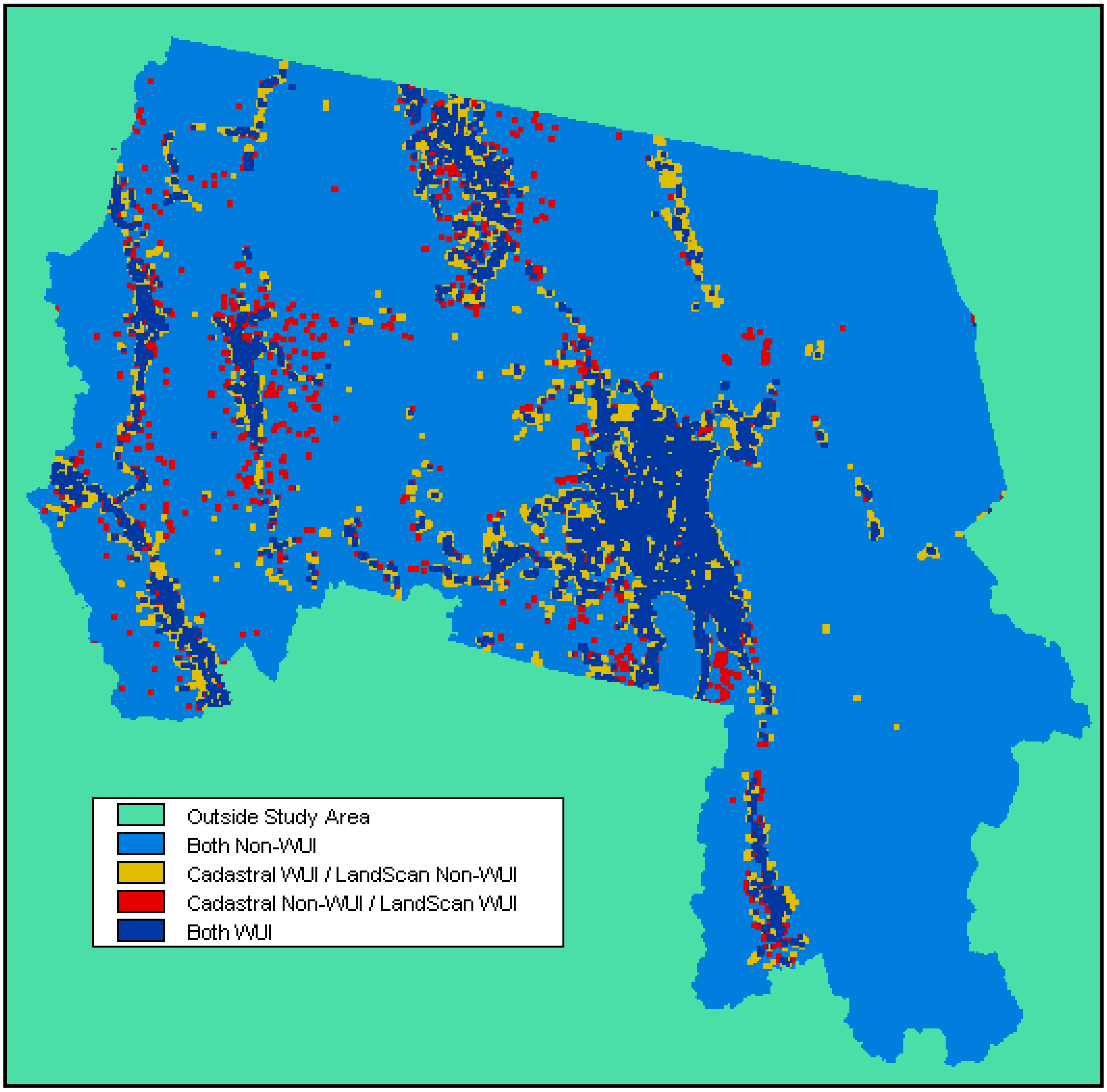

Figure 35. LandScan - Cadastral 0.336-mile buffer WUI Map.

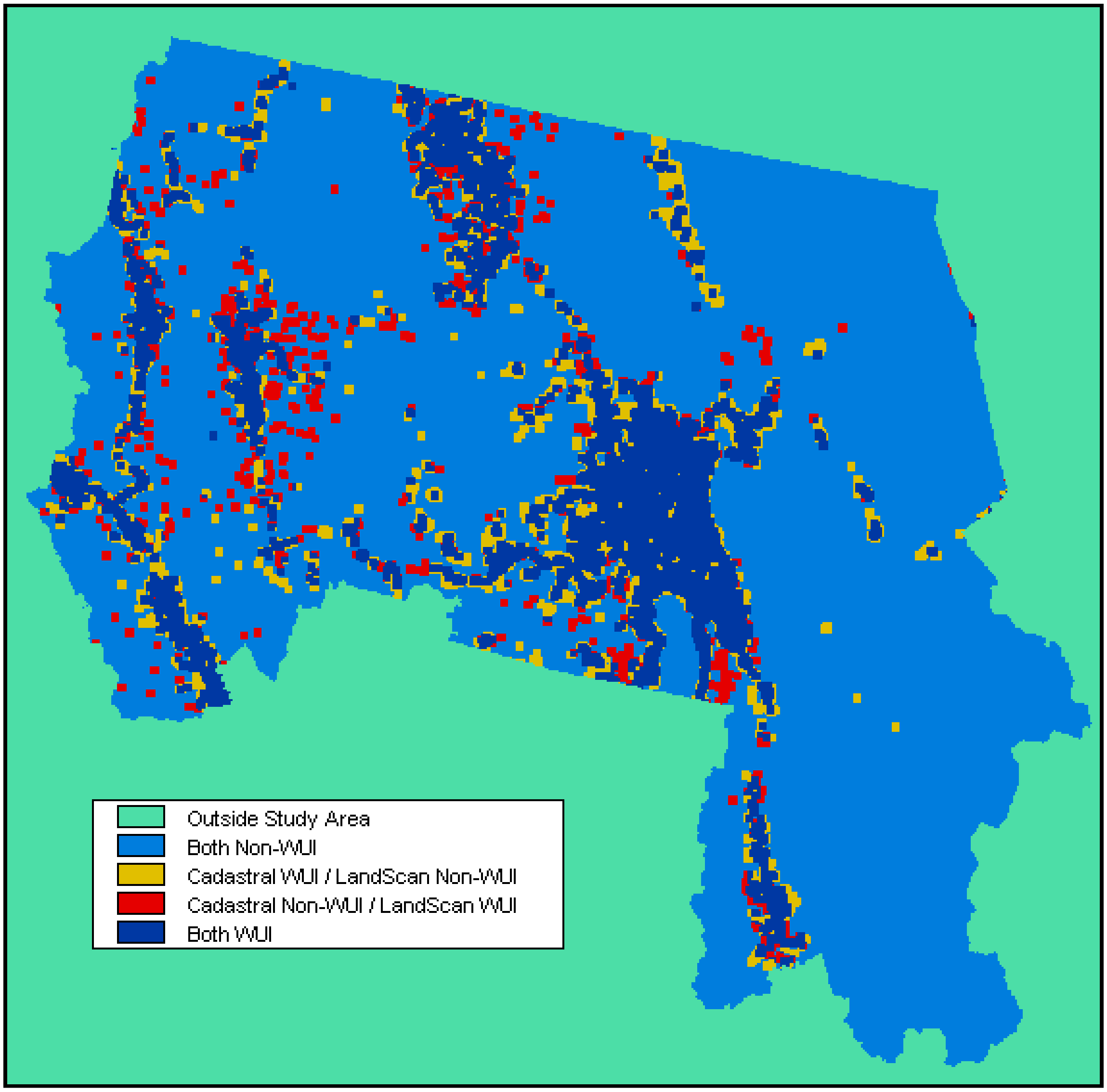

Figure 36. LandScan - Cadastral 0.503-mile buffer WUI Map.

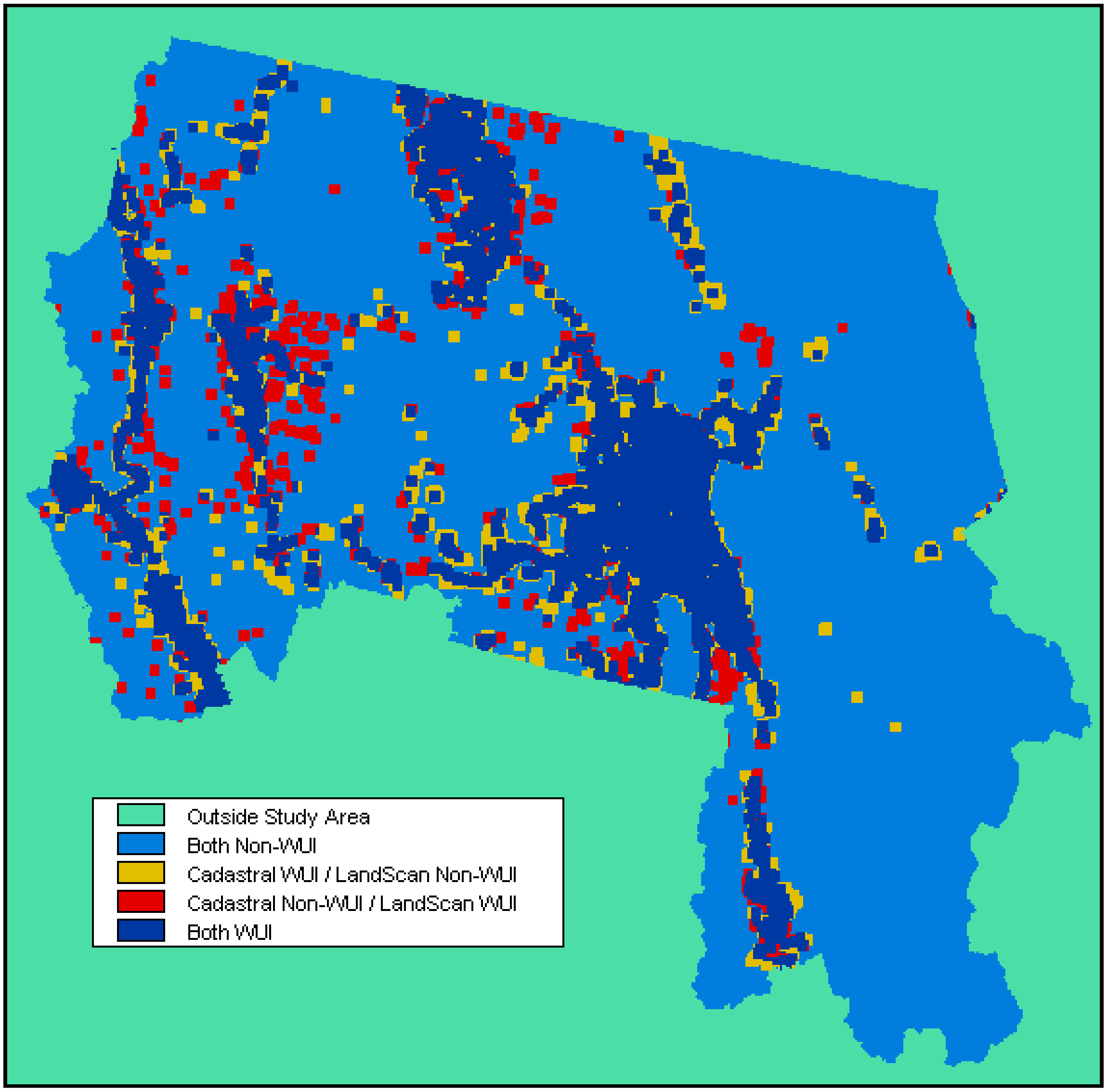

Figure 37. LandScan - Cadastral 0.671-mile buffer WUI Map.

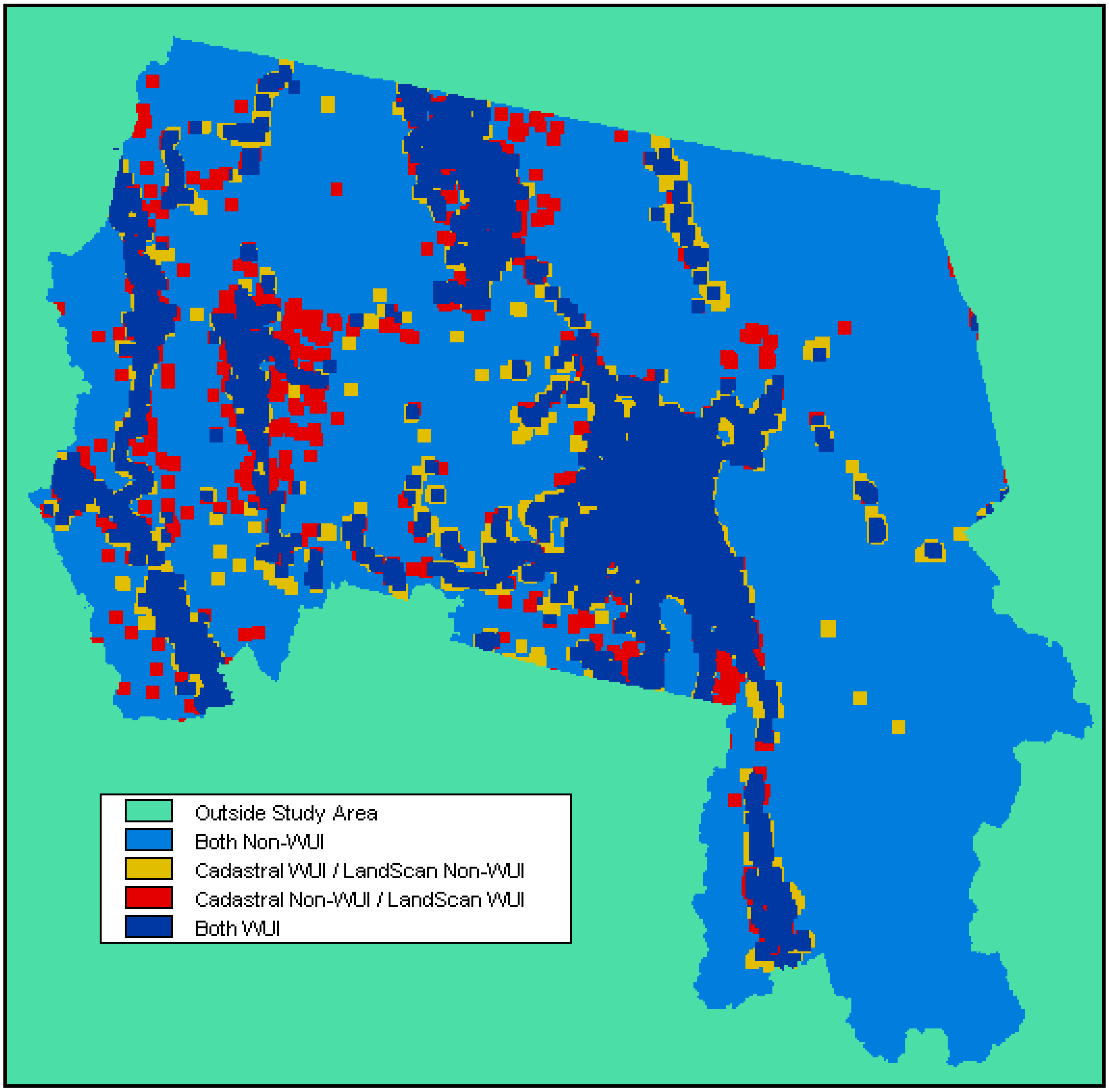

Figure 38. LandScan - Cadastral 0.839-mile buffer WUI Map.

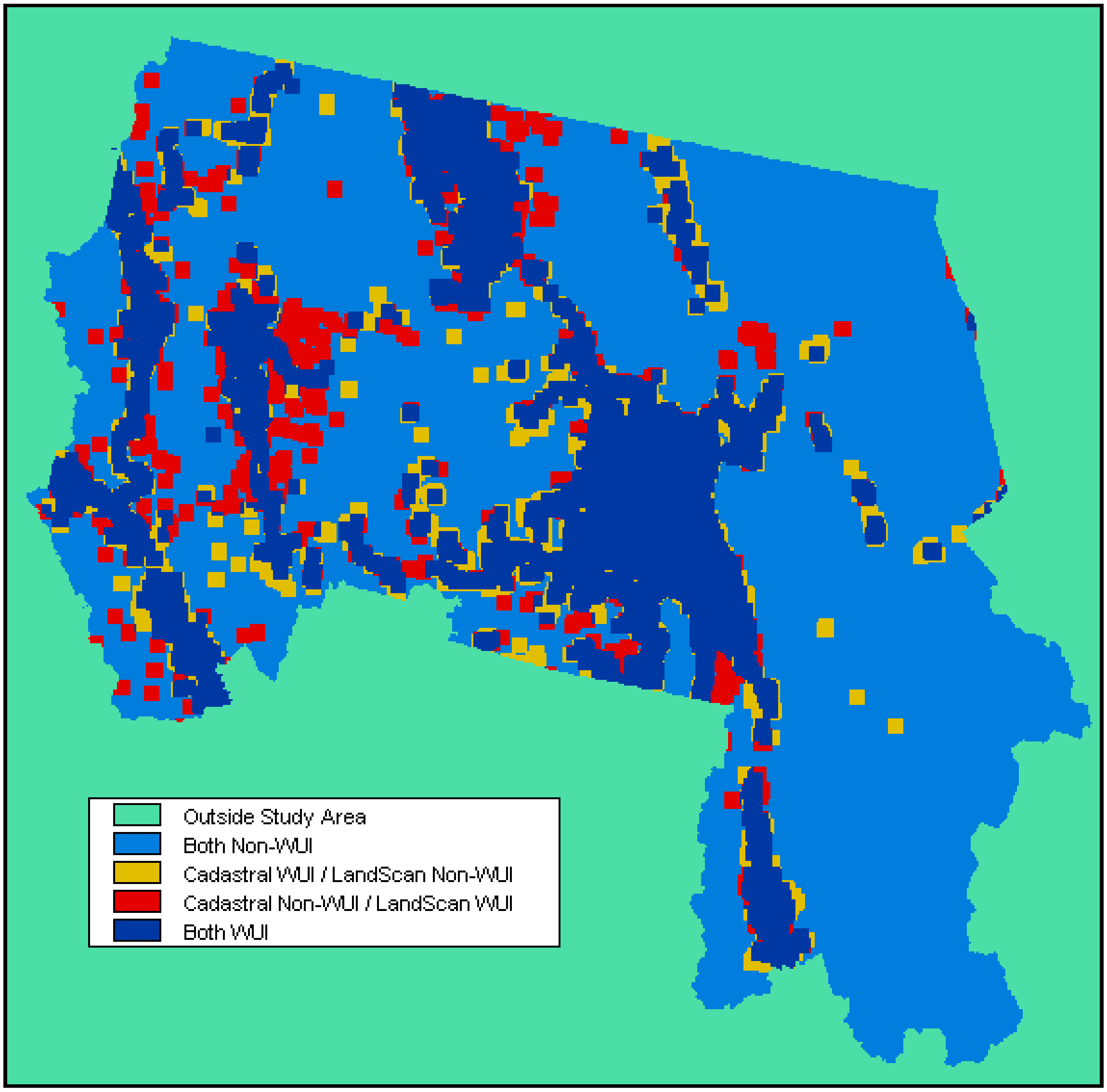

Figure 39. LandScan - Cadastral 1.007-mile buffer WUI Map.

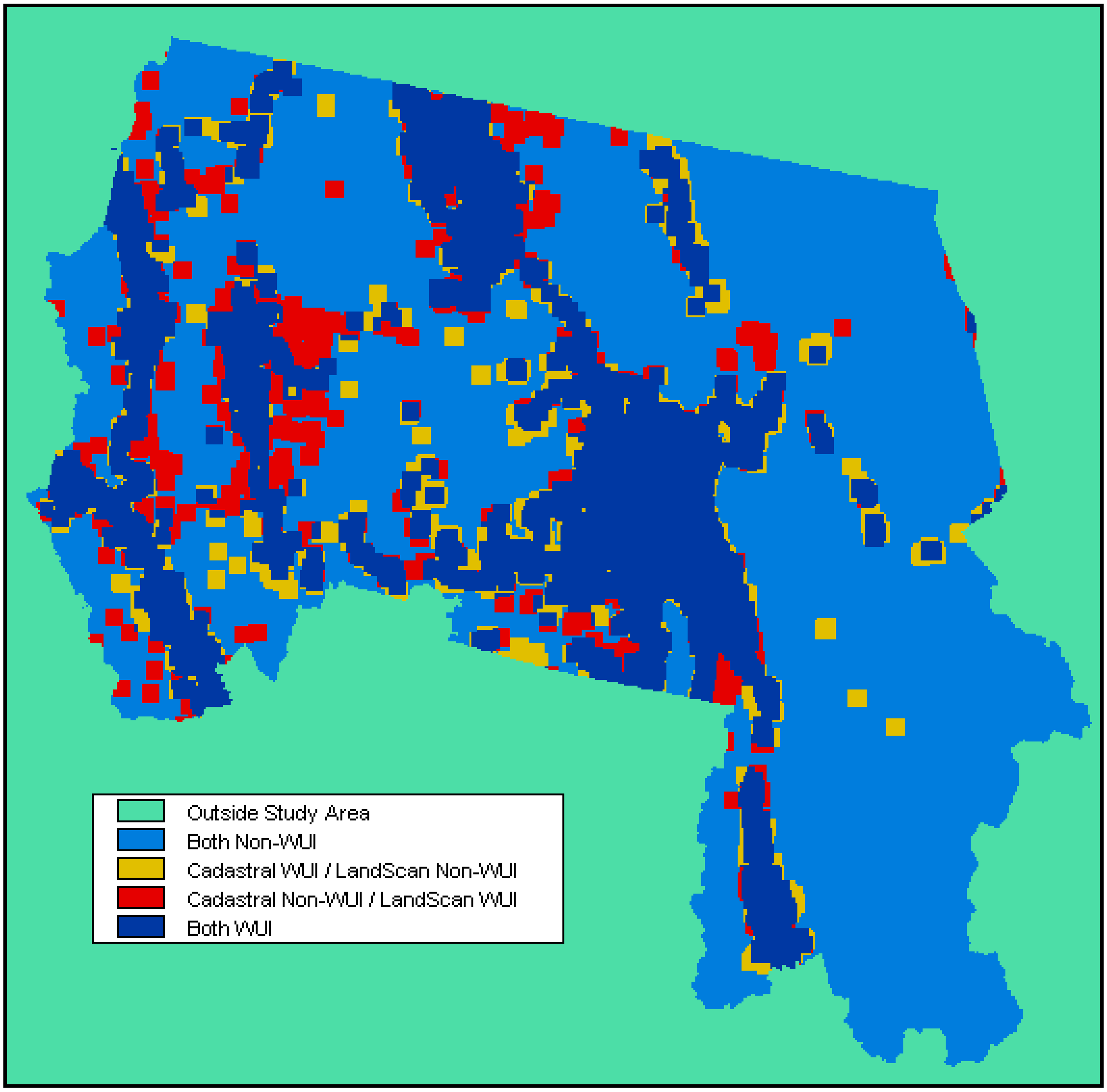

Figure 40. LandScan - Cadastral 1.174-mile buffer WUI Map.

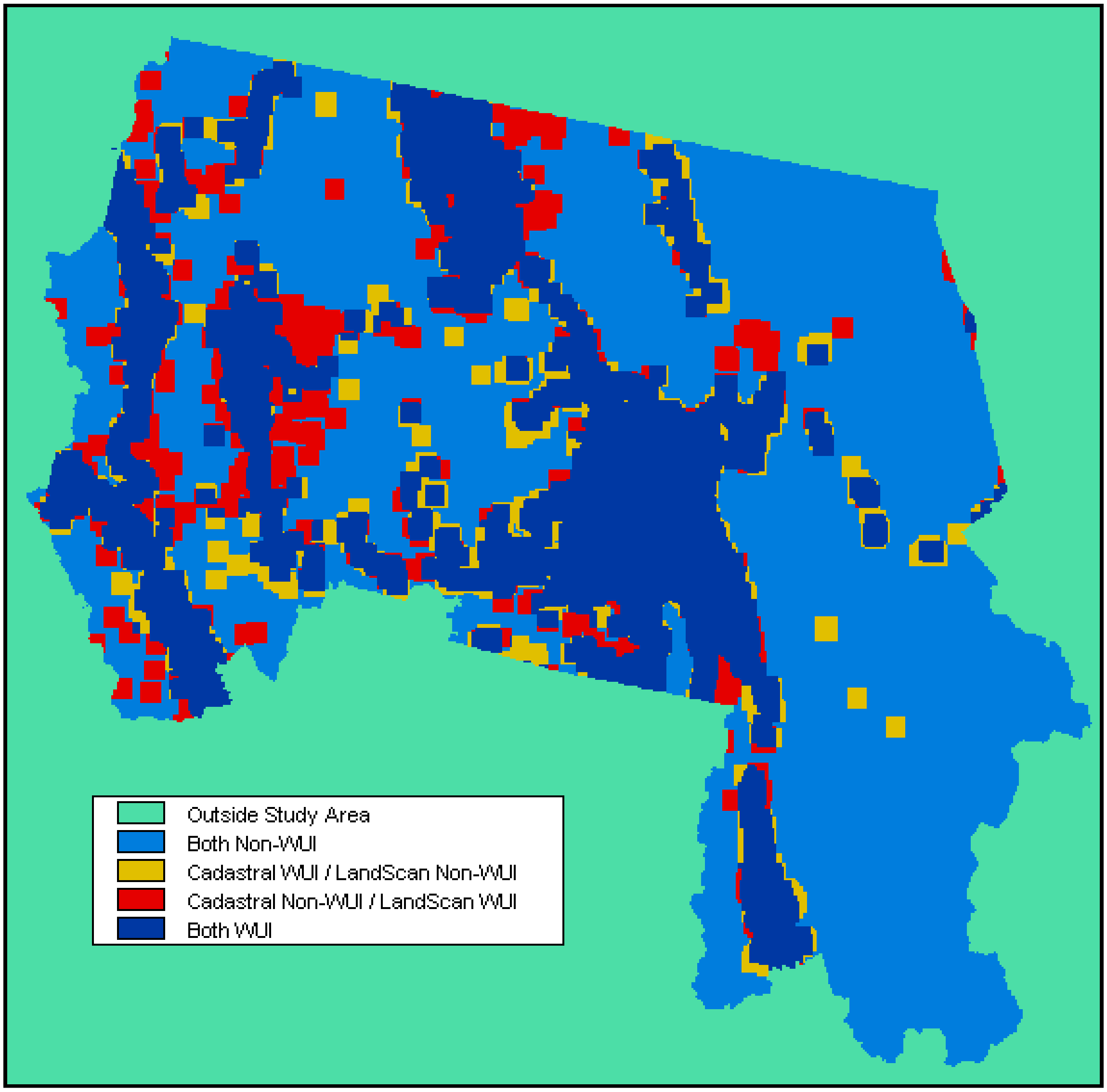

Figure 41. LandScan - Cadastral 1.342-mile buffer WUI Map.

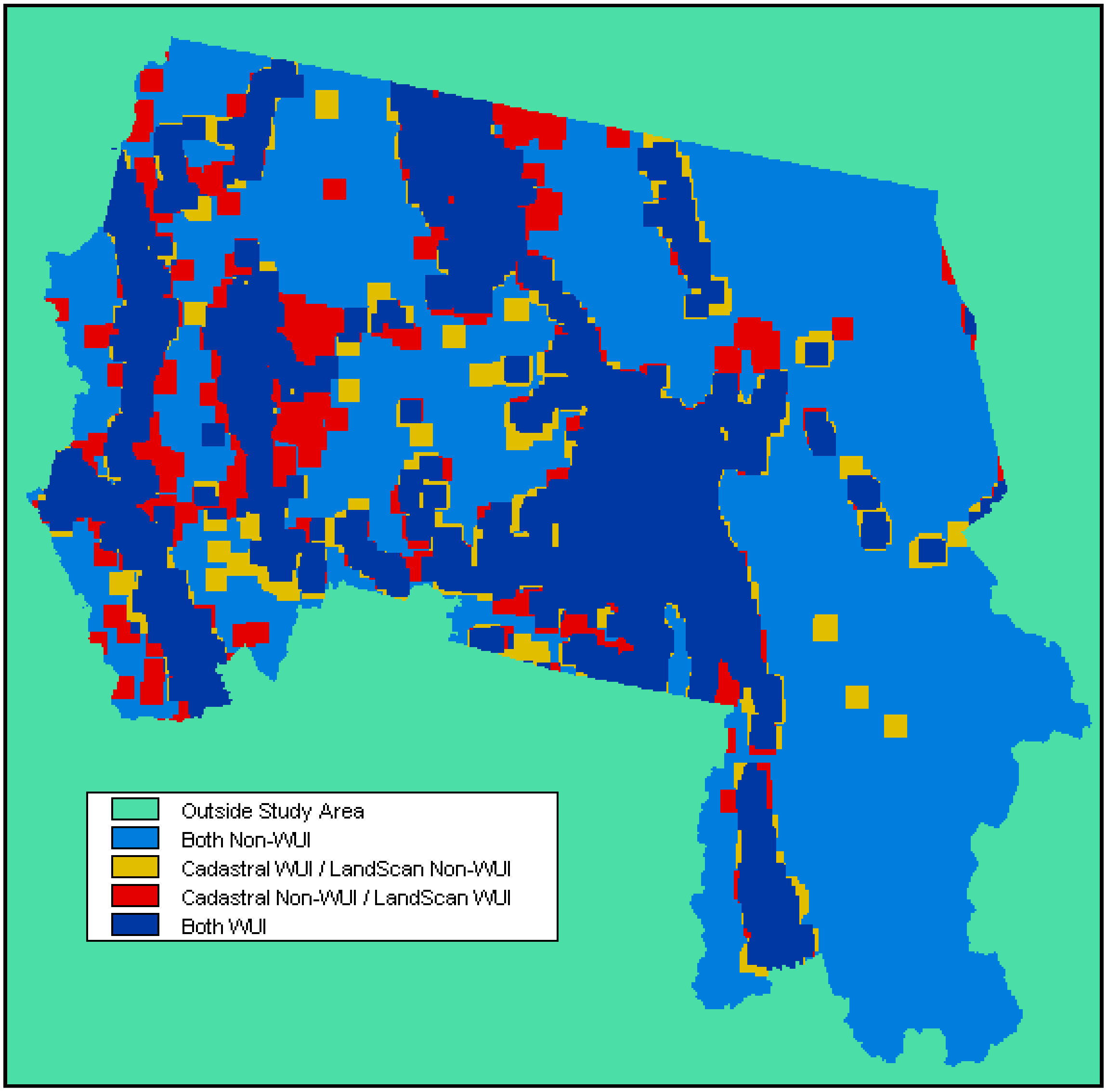

Figure 42. LandScan - Cadastral 1.510-mile buffer WUI Map.